Novel Gas-based Detection Techniques

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on behalf of the
GridPix/Gossip group

PSD8
Glasgow, Scotland, UK
Sept 1, 2008

Some history on gaseous detectors

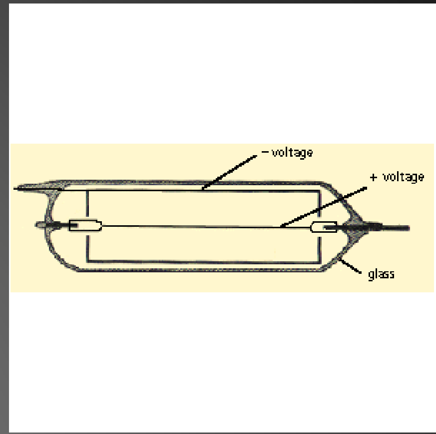
Geiger Tube 1908! 100 years ago!

Geiger-Muller tube: 1928
Proportional tube 1945

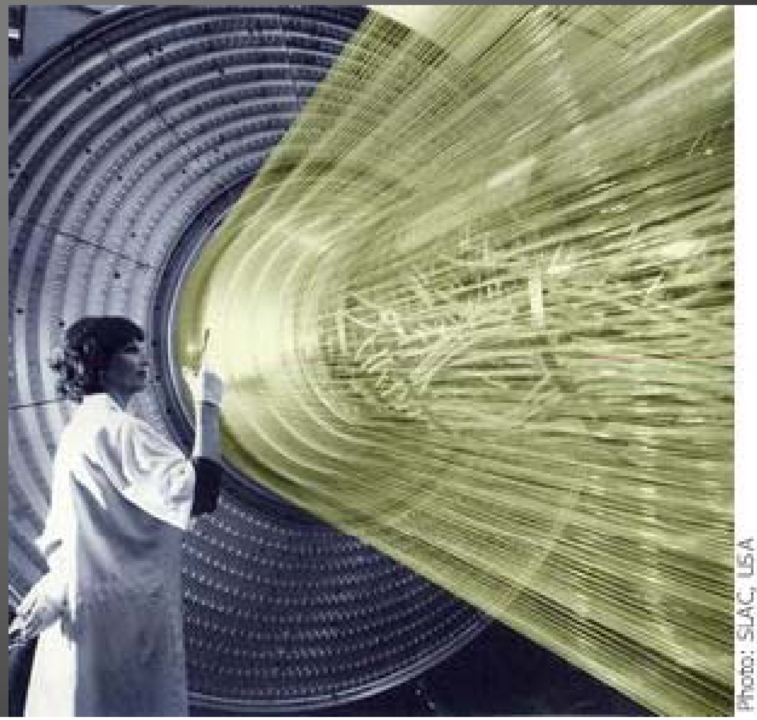
Spark Chambers

Multi Wire Proportional Chamber
1968 Charpak & Sauli
Drift Chambers, TPCs

Scintillators
Photographic emulsion



100 years ago
Hans Geiger operated first gaseous detector in Manchester, UK, 1908



Essentials: - creation of electron-ion pairs by radiation, therefore
- free drifting electrons
- in strong (1/R) field near wire: gas amplification: avalanches

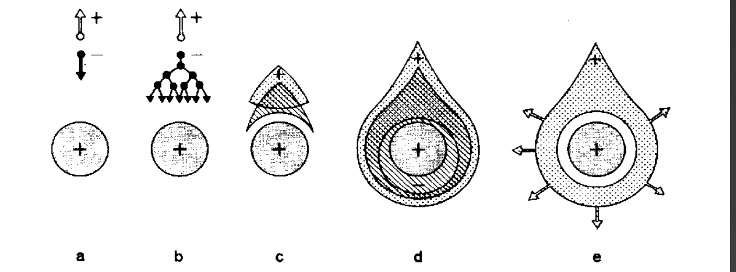
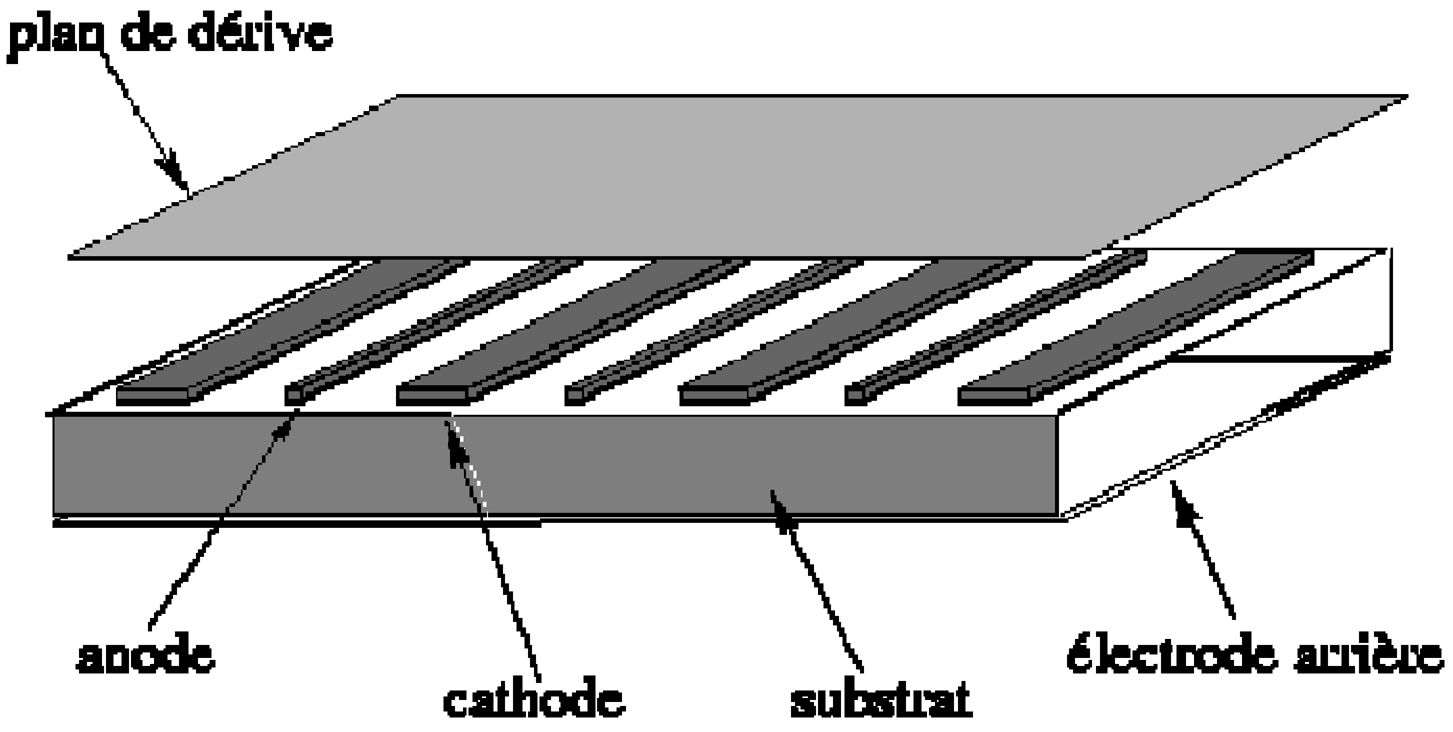


Fig. 49 Time development of an avalanche in a proportional counter[30]. A single primary electron proceeds towards the anode, in regions of increasingly high fields, experiencing ionizing collisions; due to the lateral diffusion, a drop-like avalanche, surrounding the wire, develops. Electrons are collected in a very short time (1 nsec or so) and a cloud of positive ions is left, slowly migrating towards the cathode.

But: - wires can't be fixed closer than 1 mm pitch
- 'integrate' in direction along wire

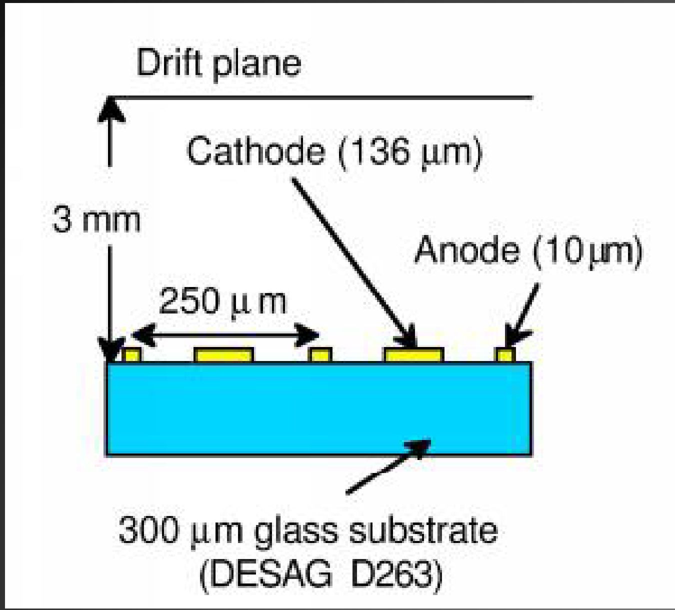
Bad granularity:
- occupancy problem
- bad spatial resolution ➔ 1980: Si Detectors!
nice narrow strips, small pixels

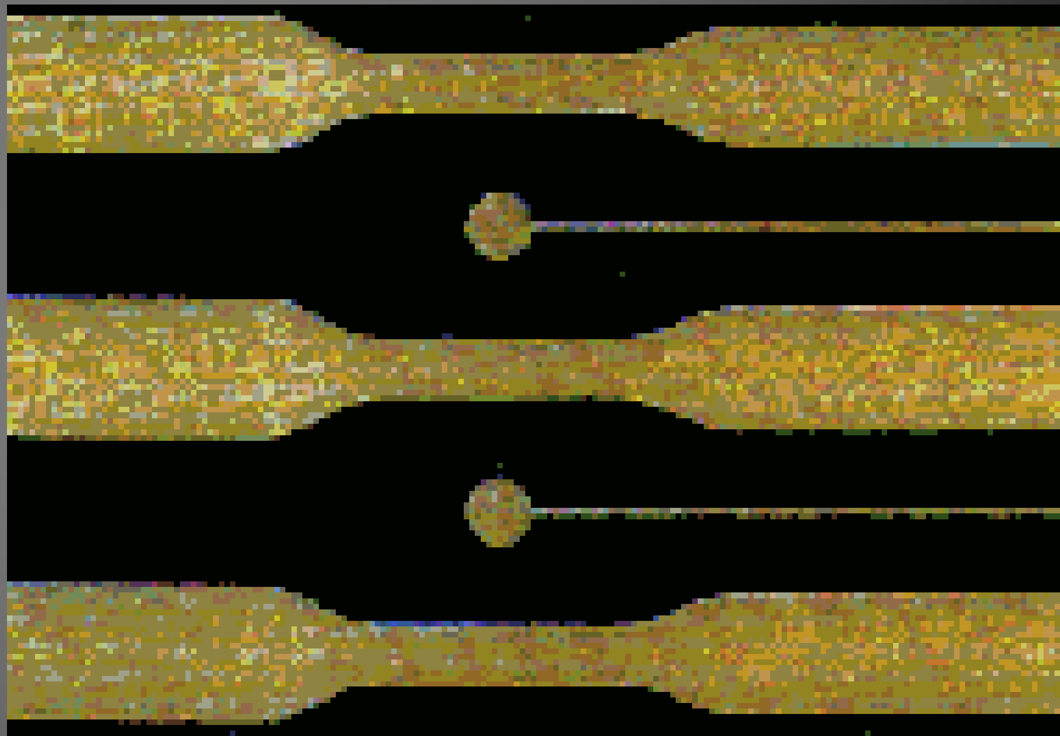
Micro Strip Gas Counter



Wire chambers:	granularity ~ 1 mm
MSGCs:	granularity 200 μm

Invented by A. Oed, 1988



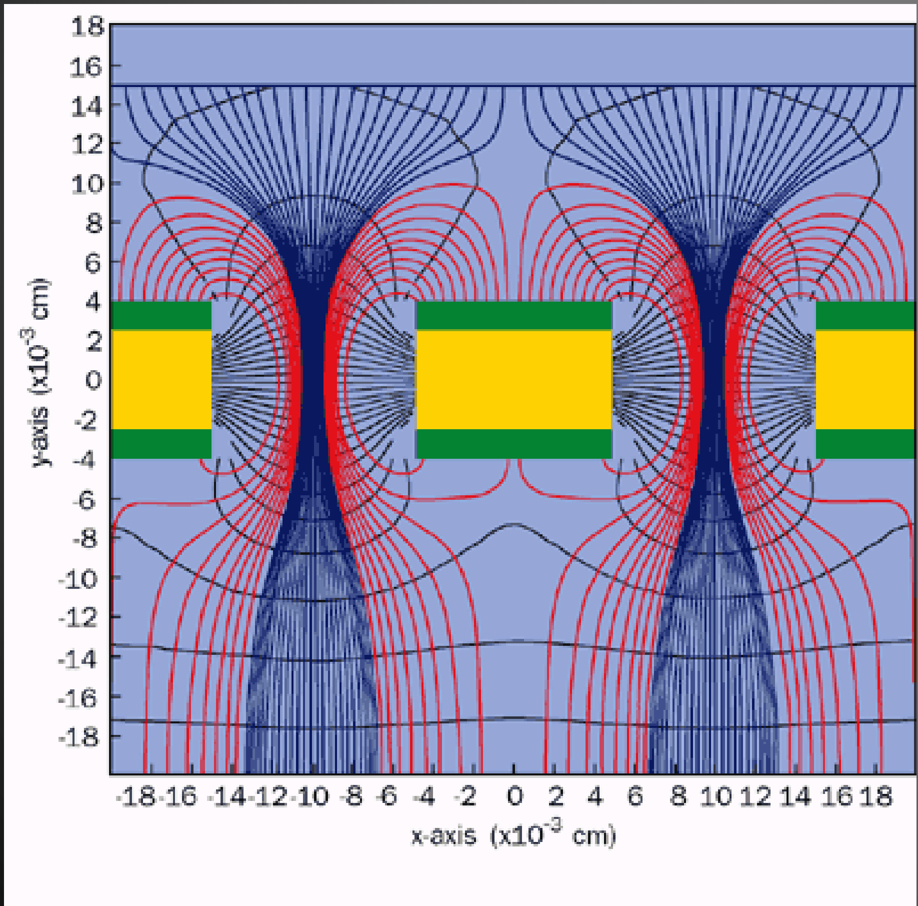


Not often applied:

…sparks……!

Let us eliminate wires: wireless wire chambers

1996: F. Sauli: Gas Electron Multiplier (GEM)



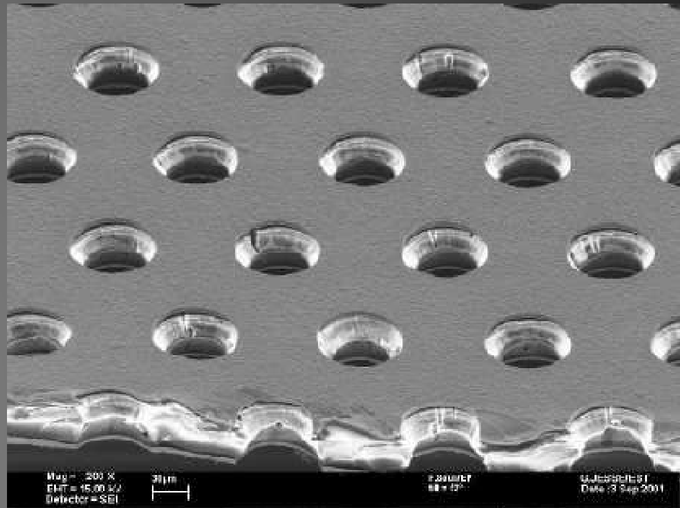


Fig. 7

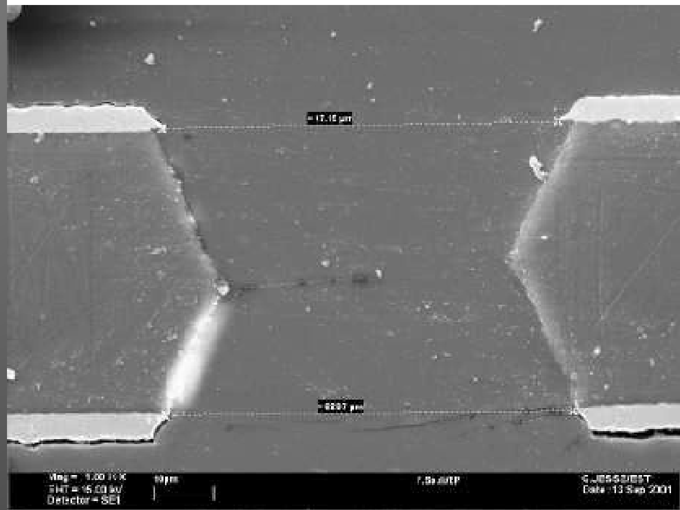
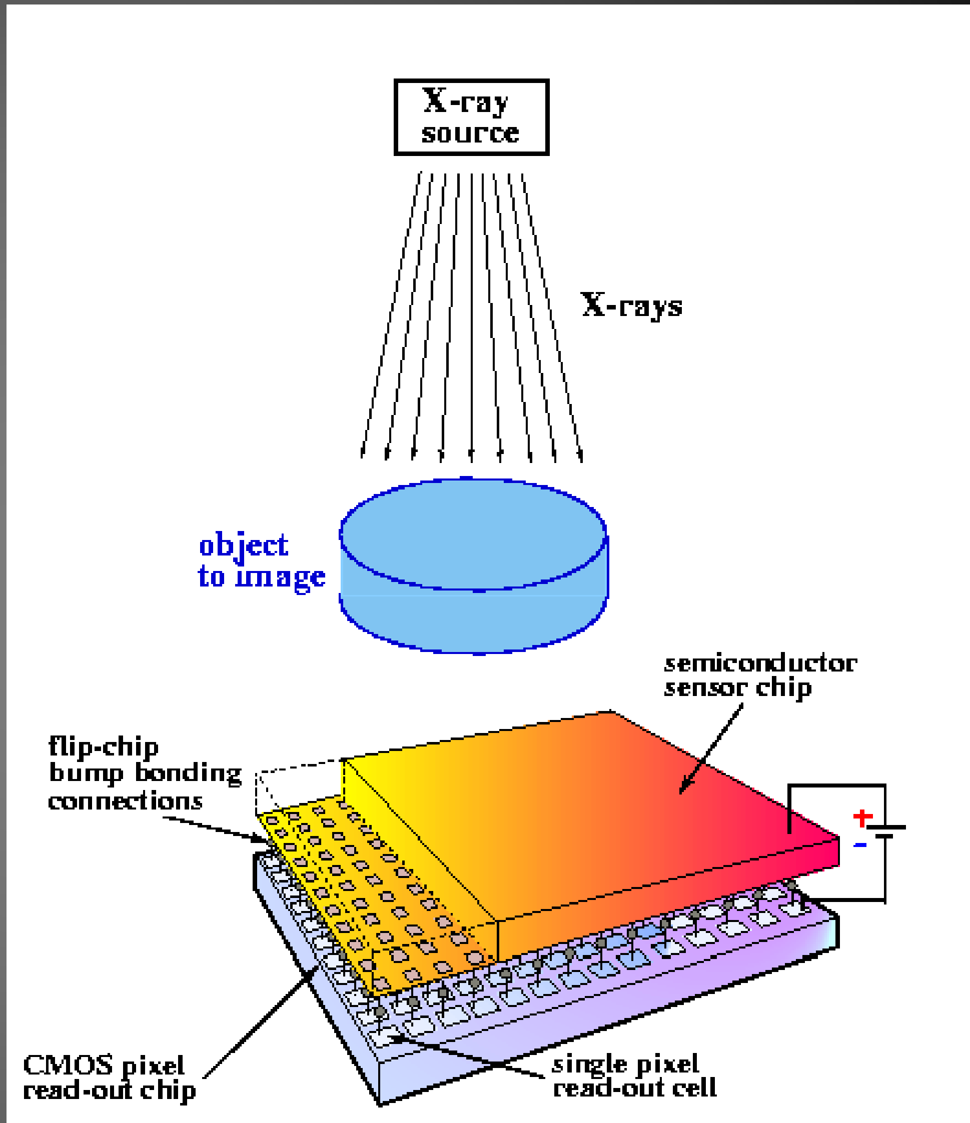


Fig. 8

The MediPix2 pixel CMOS chip

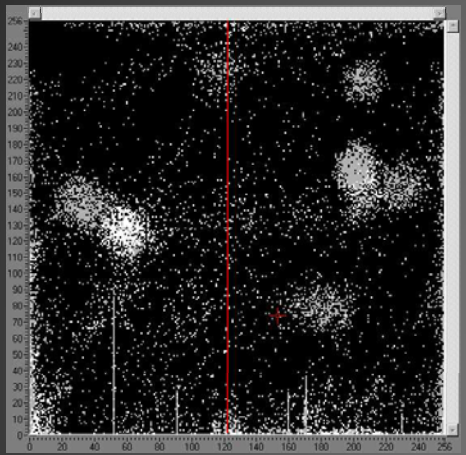
256 x 256 pixels
pixel: 55 x 55 μm^2
per pixel:
- preamp
- shaper
- 2 discr.
- Thresh. DAQ
- 14 bit counter

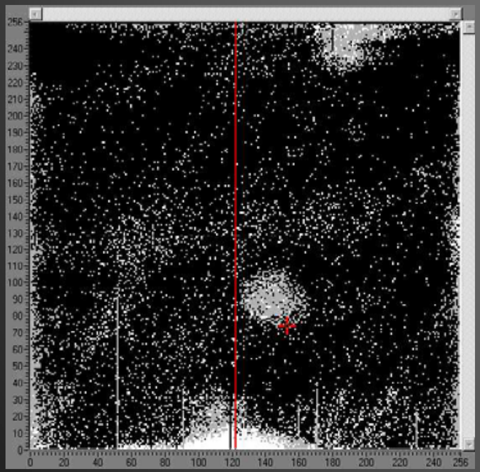
- enable counting
- stop counting
- readout image frame
- reset

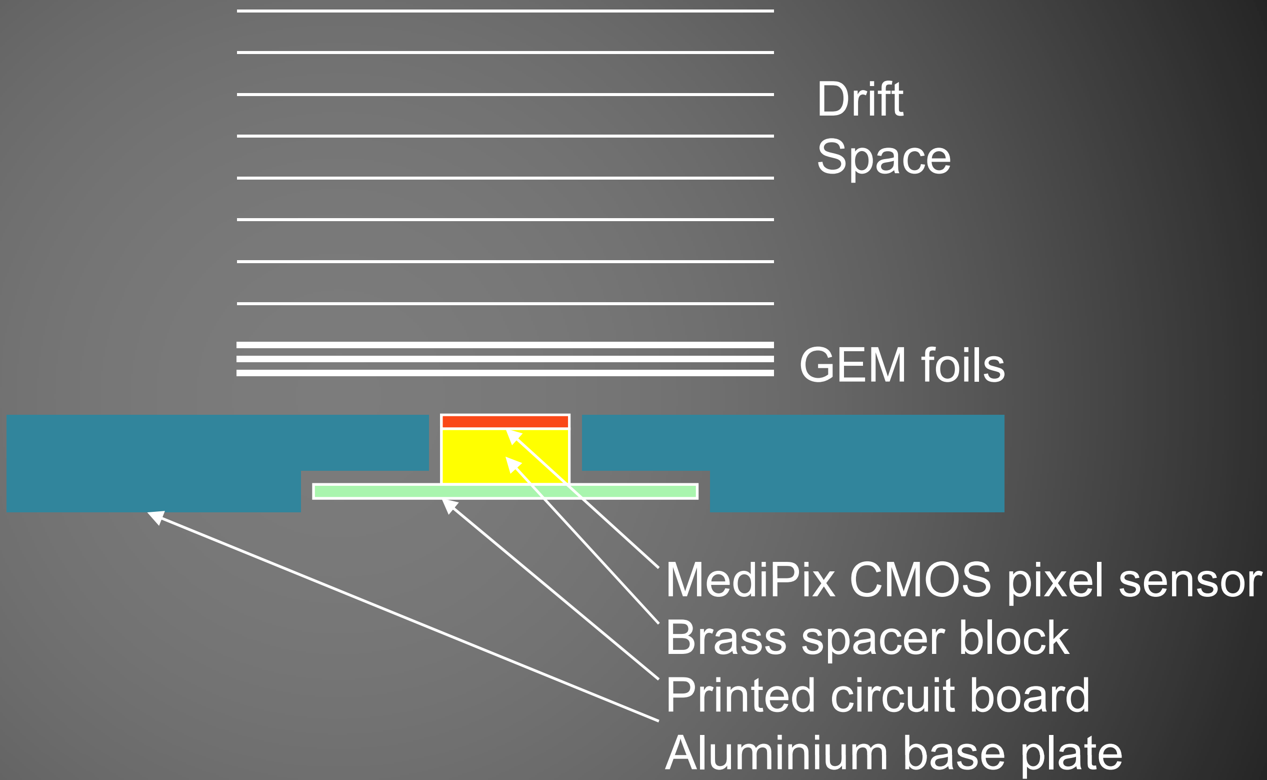


We apply the 'naked' MediPix2 chip without X-ray convertor!

March 29, 2003



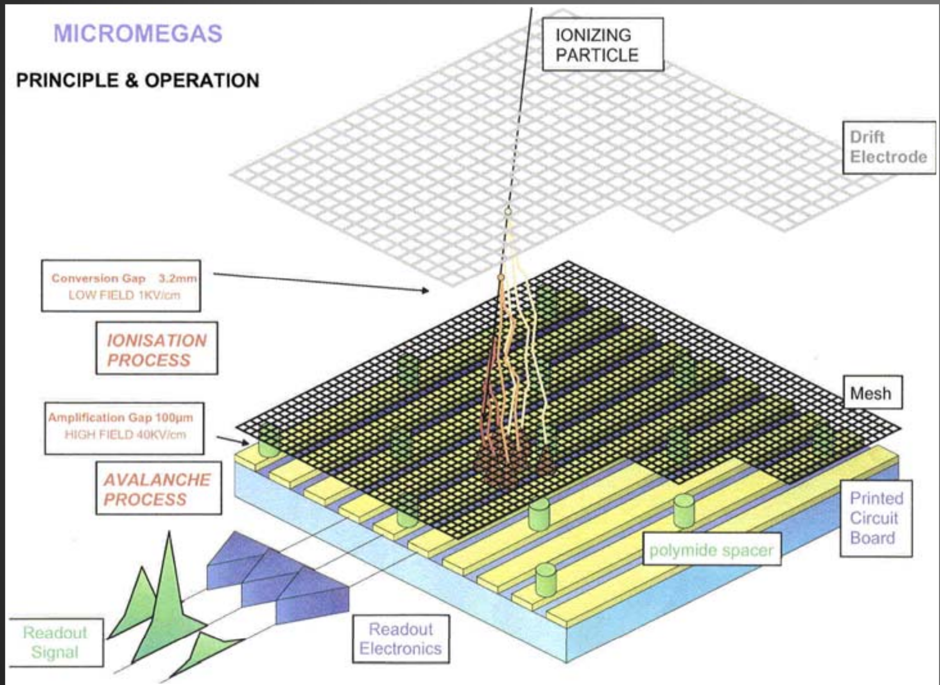


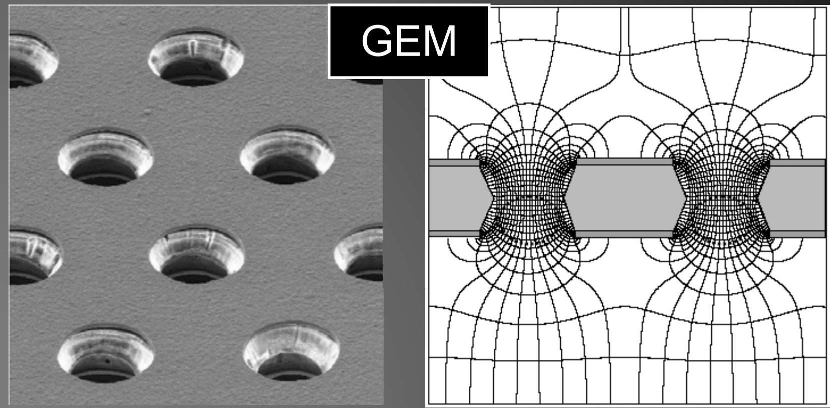


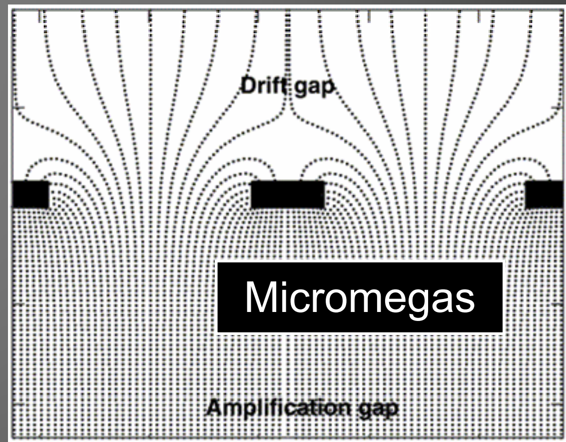
First events, recorded on March 29, 2003.
Drift space irradiated with ^{55}Fe quanta
Gas: Ar/Methane 90/10

Micro Patterned Gaseous Detectors

- High field created by Gas Gain Grids
- Most popular: GEM & Micromegas

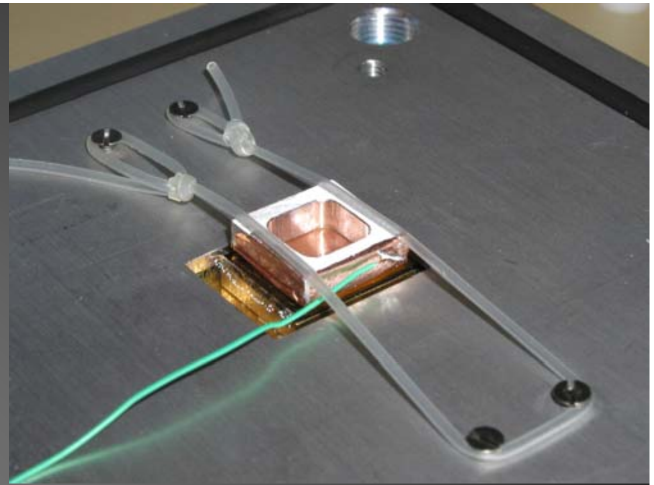


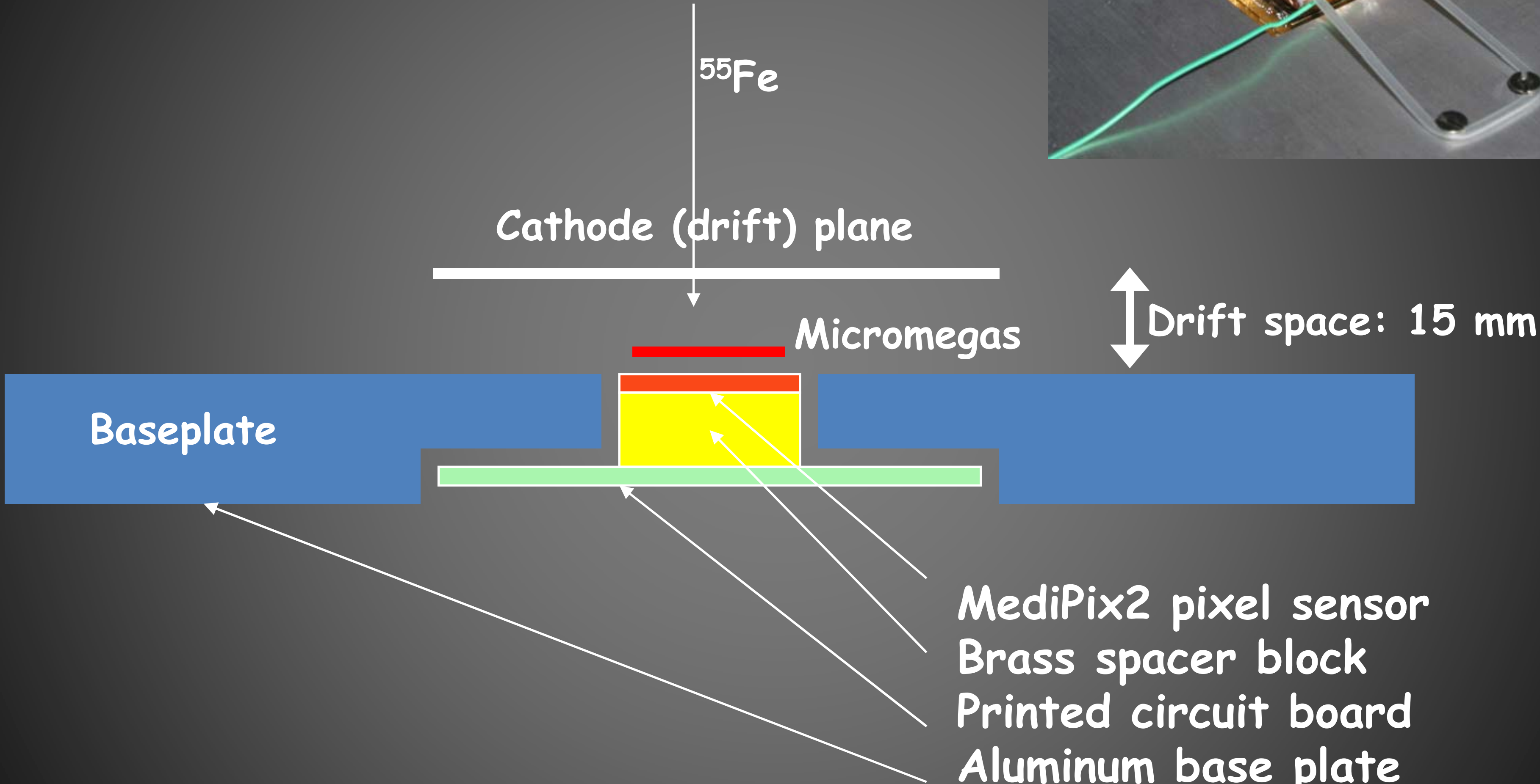




improved granularity : wire chambers react on COG of many electron clouds/clusters

MediPix2 & Micromegas:
apply the 'naked' MediPix2 chip
without X-ray convertor!



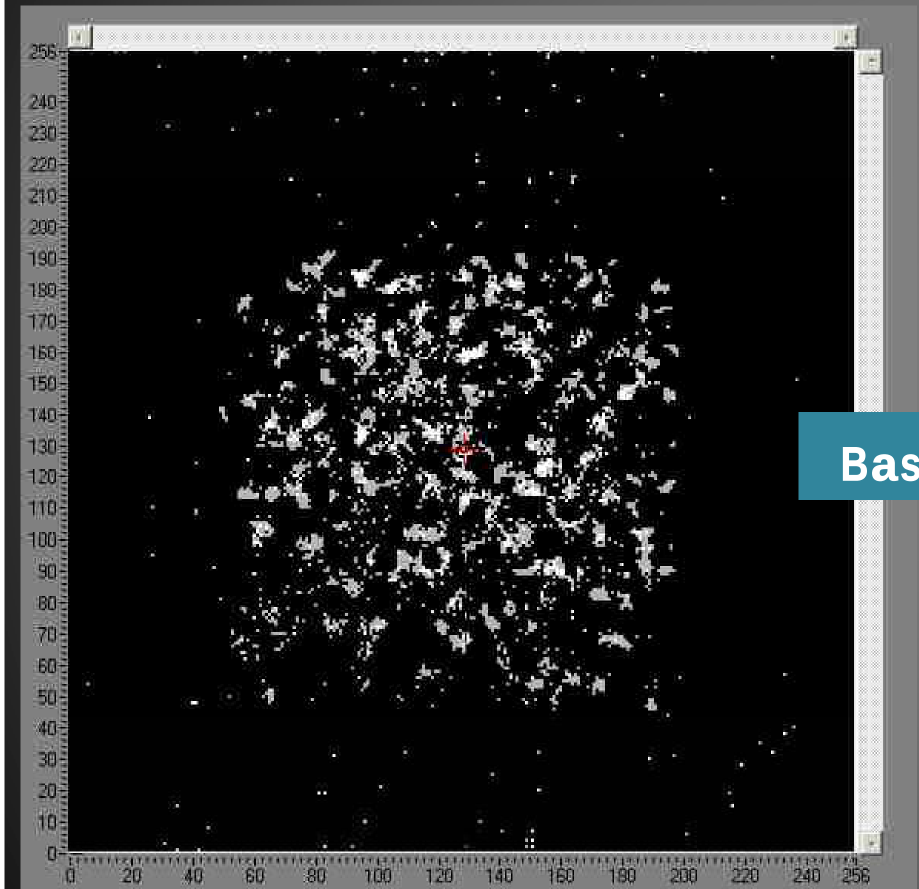


Very strong E-field above (CMOS) MediPix!

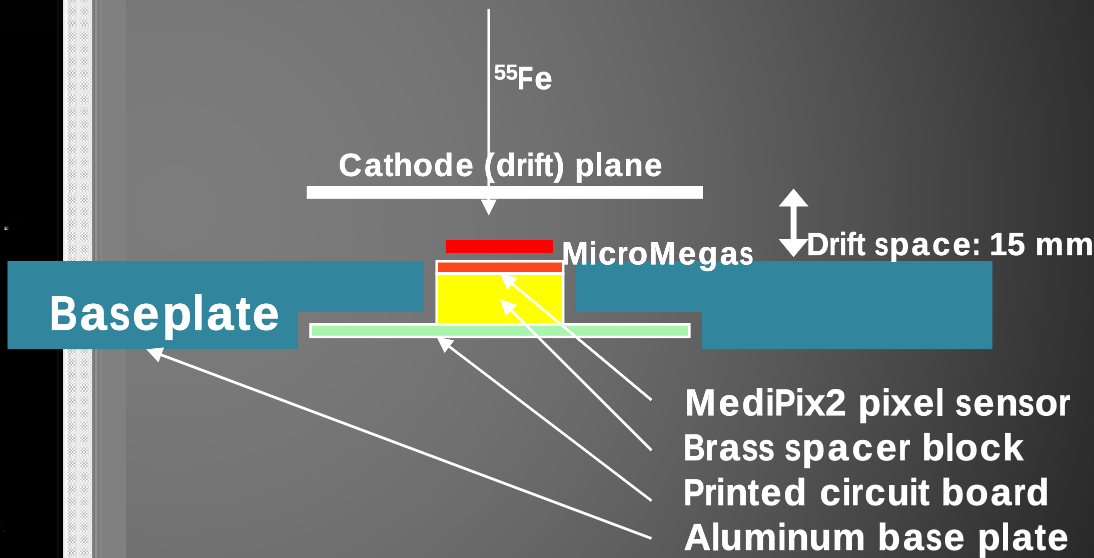
Nikhef/Saclay/Univ. Twente

February 2004

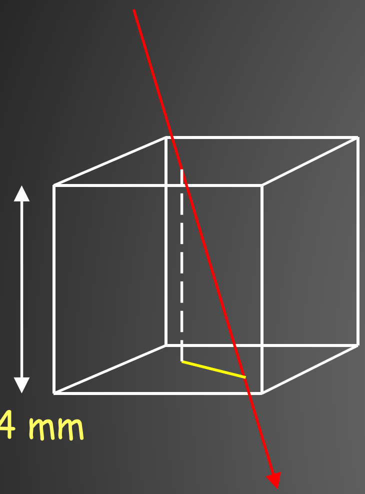
Very strong E-field above (CMOS) MediPix!



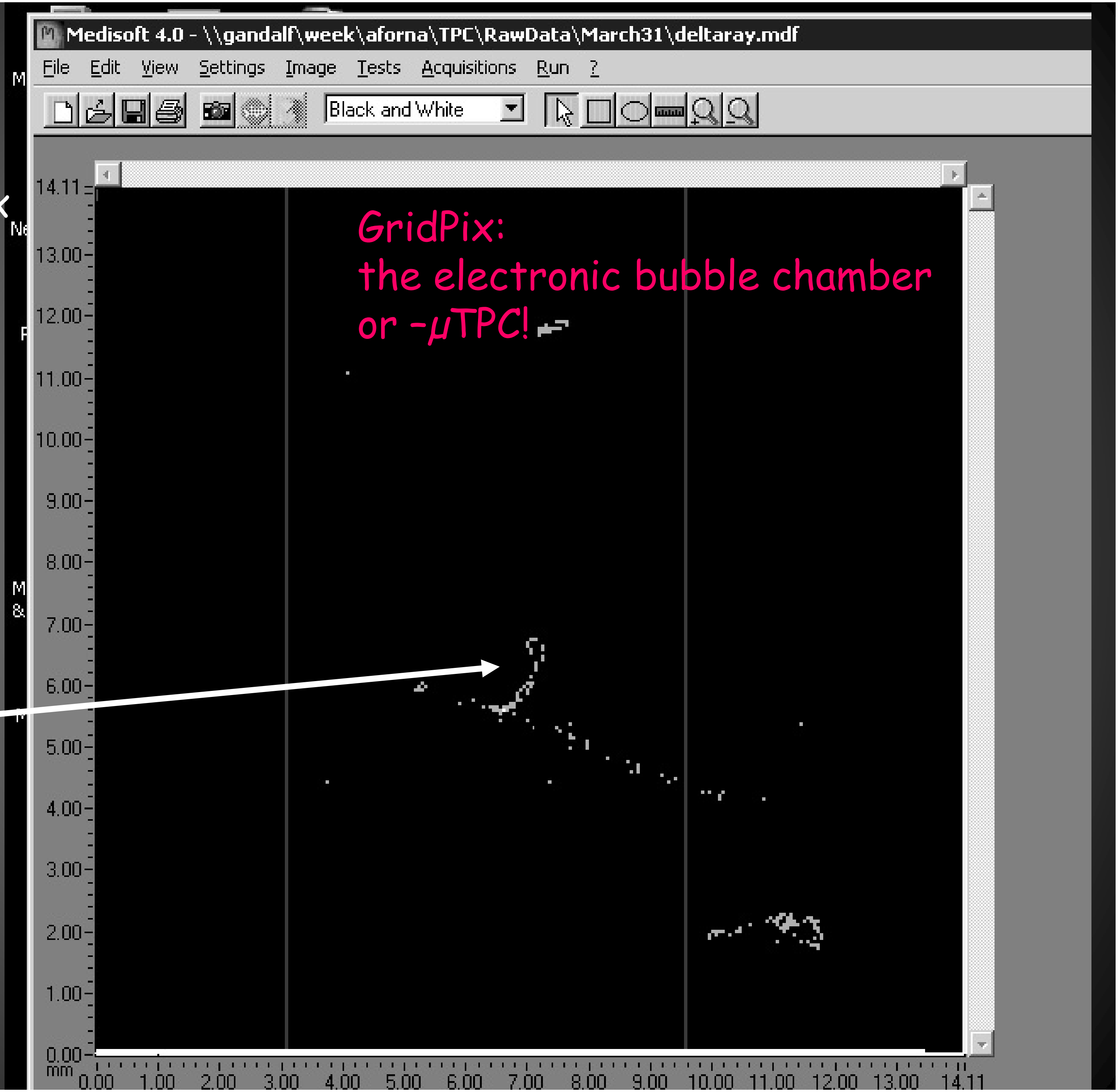
^{55}Fe



He/Isobutane
80/20
Modified MediPix



δ-ray!

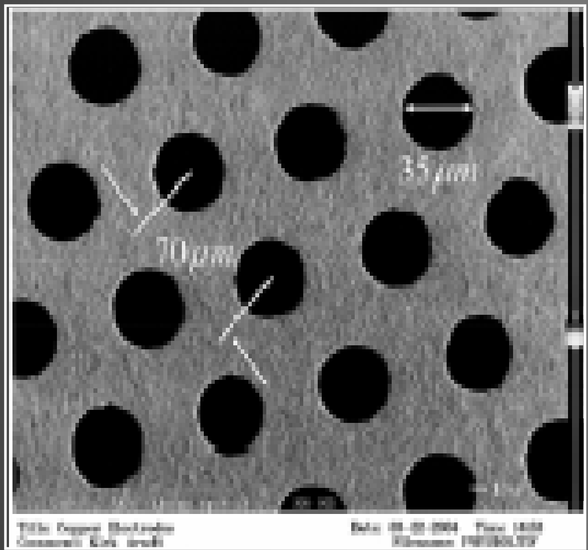


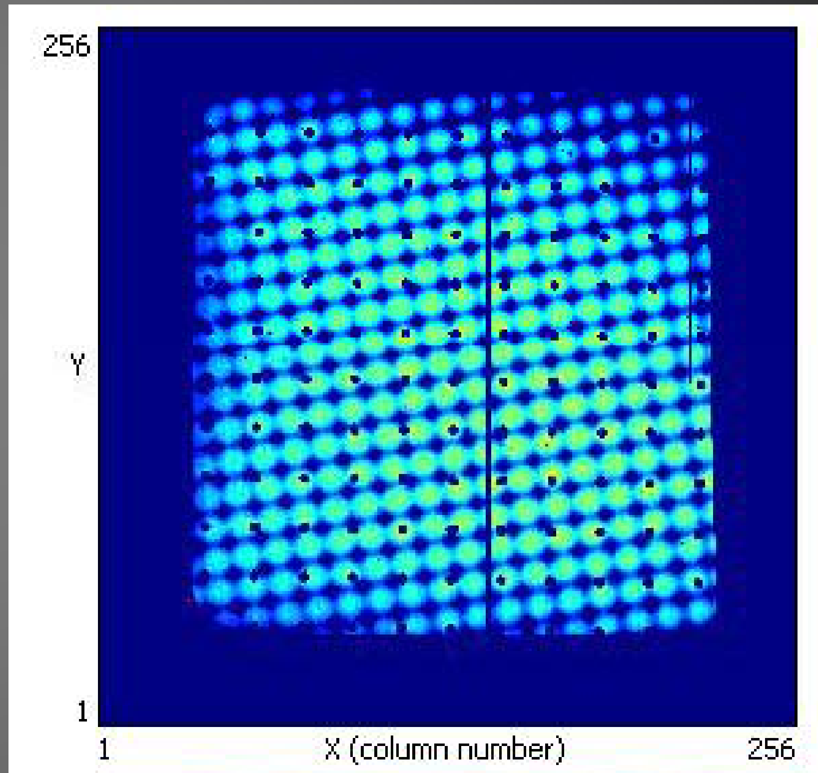
Efficiency for
detecting single
electrons:
< 95 %

MicroMegas

Timepix chip + Micromegas mesh:

CERN





Moiré effects

+ pillars

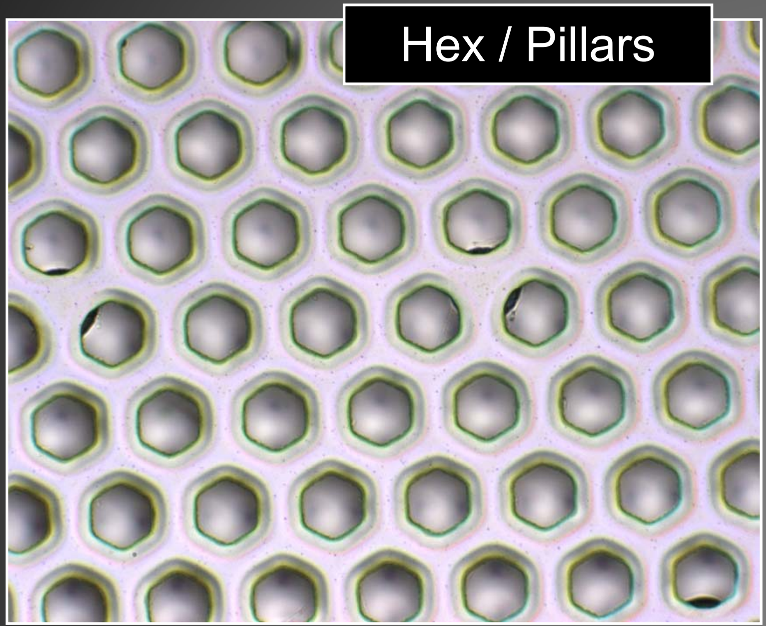
TimePix pixels: 55 μm sq
Micromegas: 60 μm sq

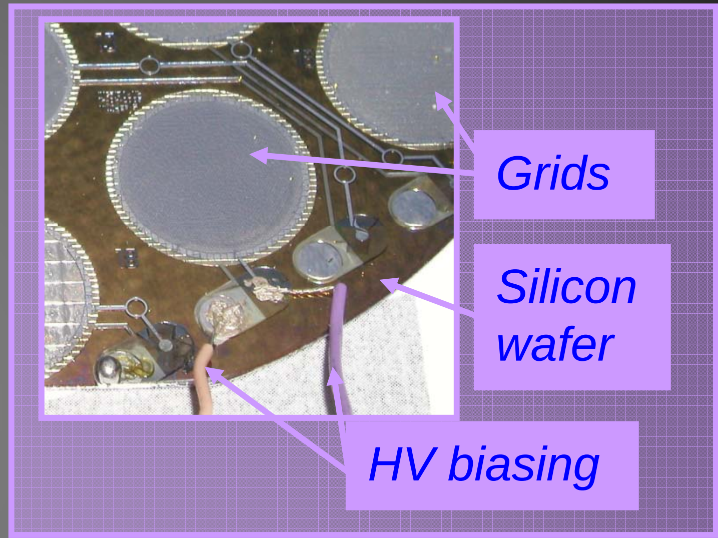
Charge mode

Wafer post-processing: InGrid

idea: Jan Visschers 2004

Granted project 'There is plenty of room at the Top'



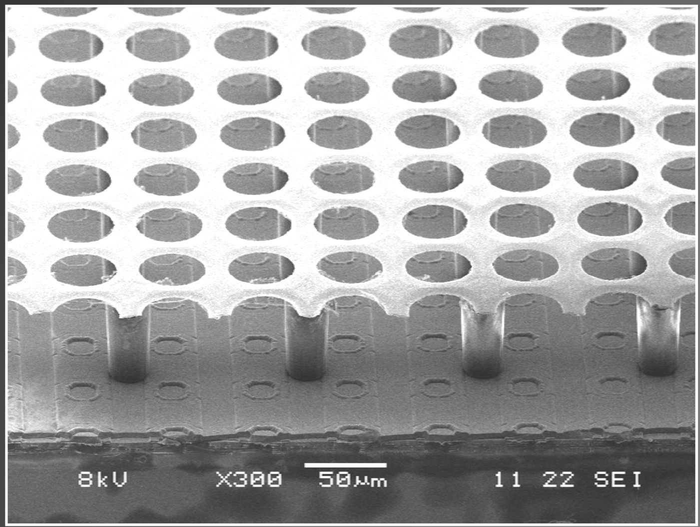


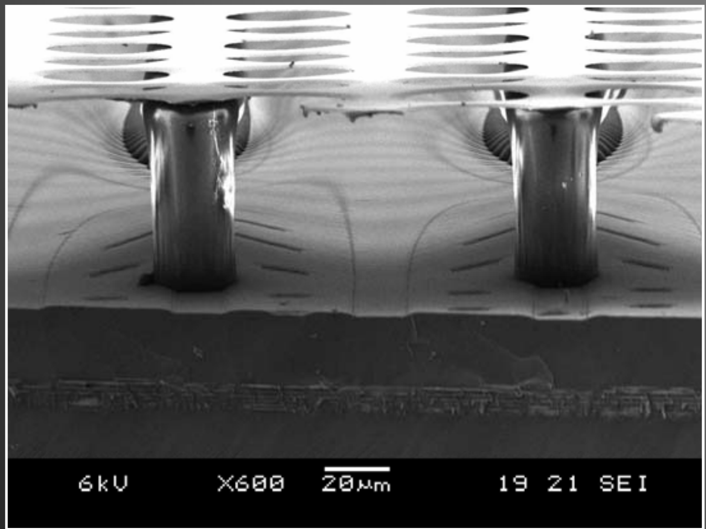
InGrid: an Integrated Grid on Si (wafers or chips)

- perfect alignment of grid holes and pixel pads
- small pillars Ø, hidden pillars, full pixel area coverage
- Sub-micron precision: homogeneity
- Monolithic readout device: integrated electron amplifier

Full post-processing of a TimePix

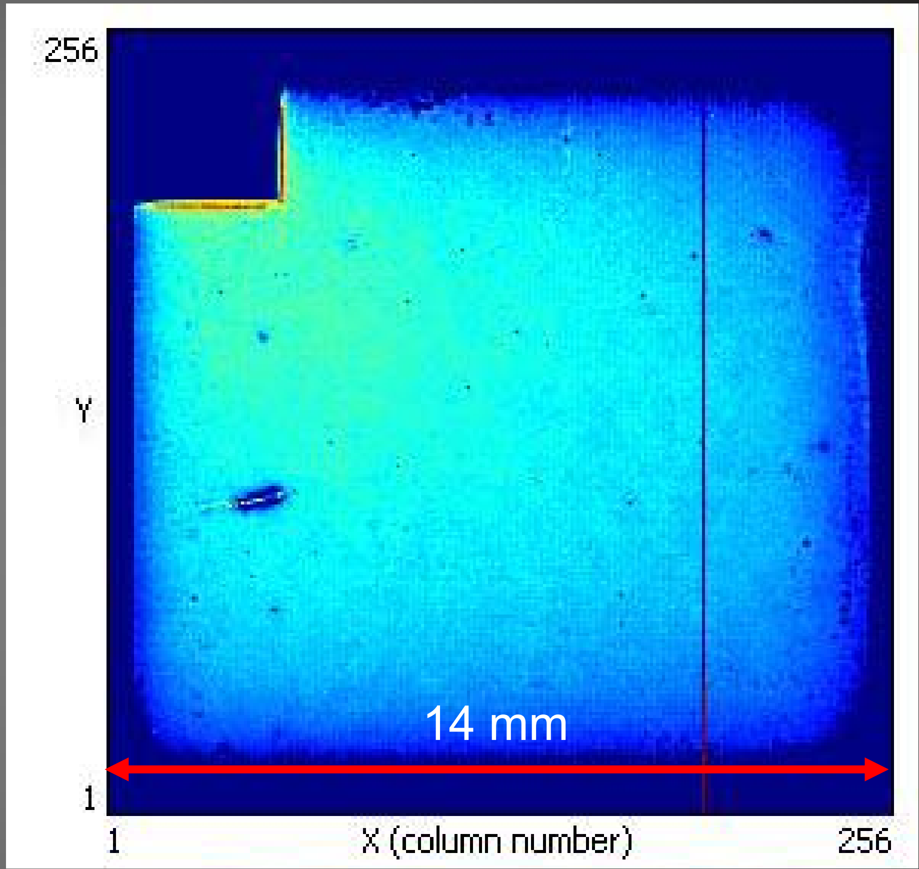
- Timepix chip + SiProt + Ingrid:





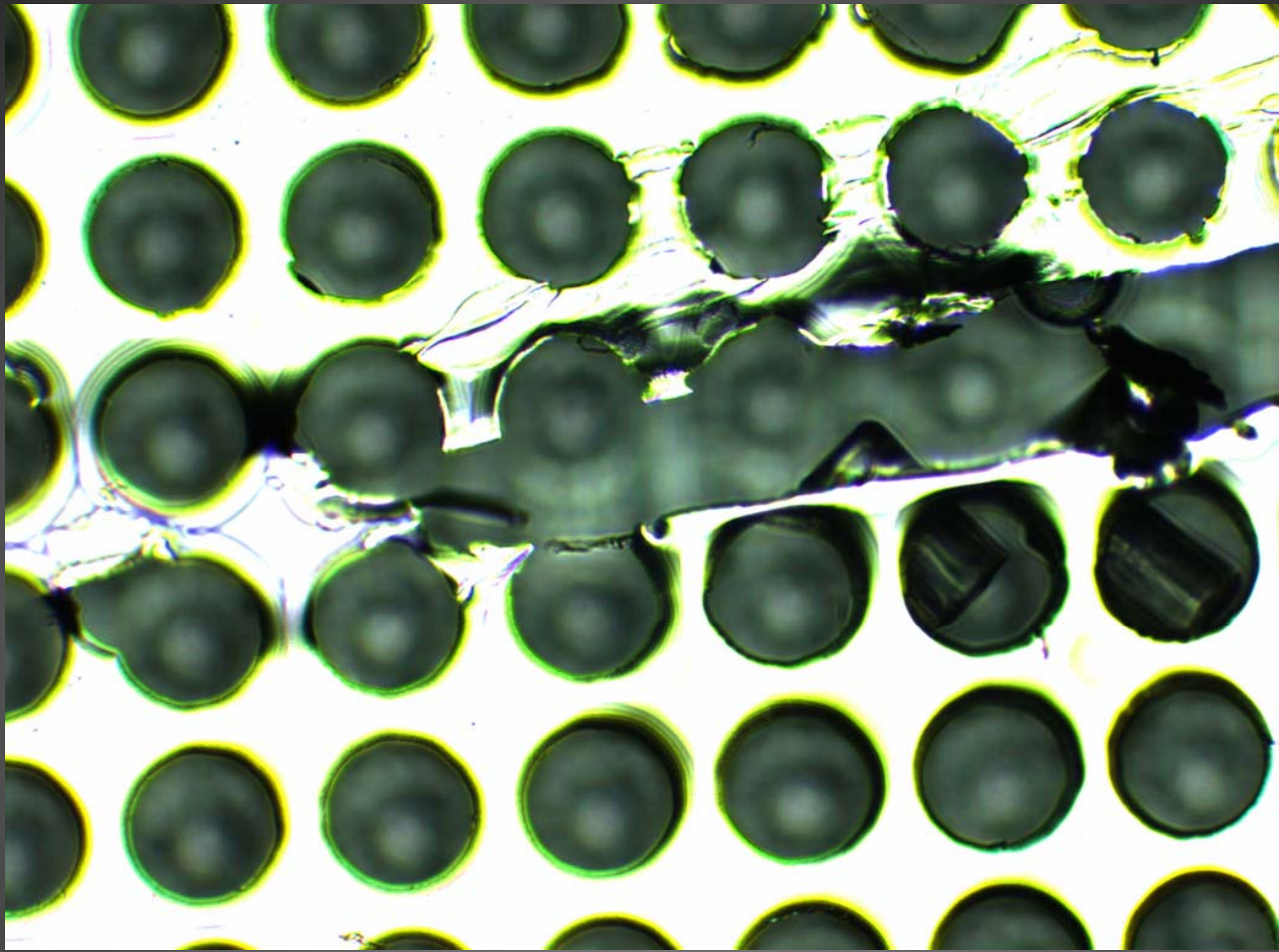
MESA+

IMT
Neuchatel



"Uniform"

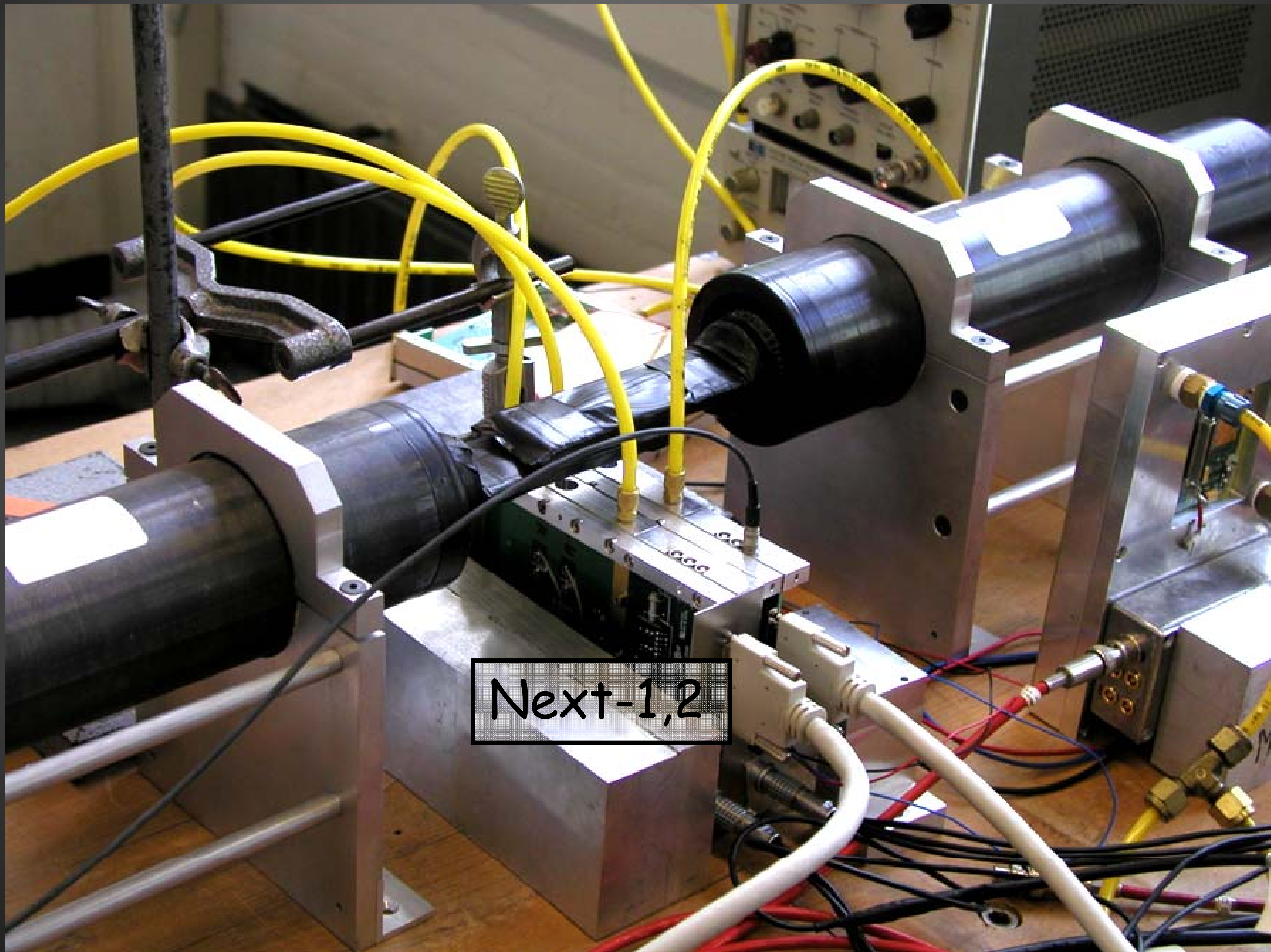
Charge mode

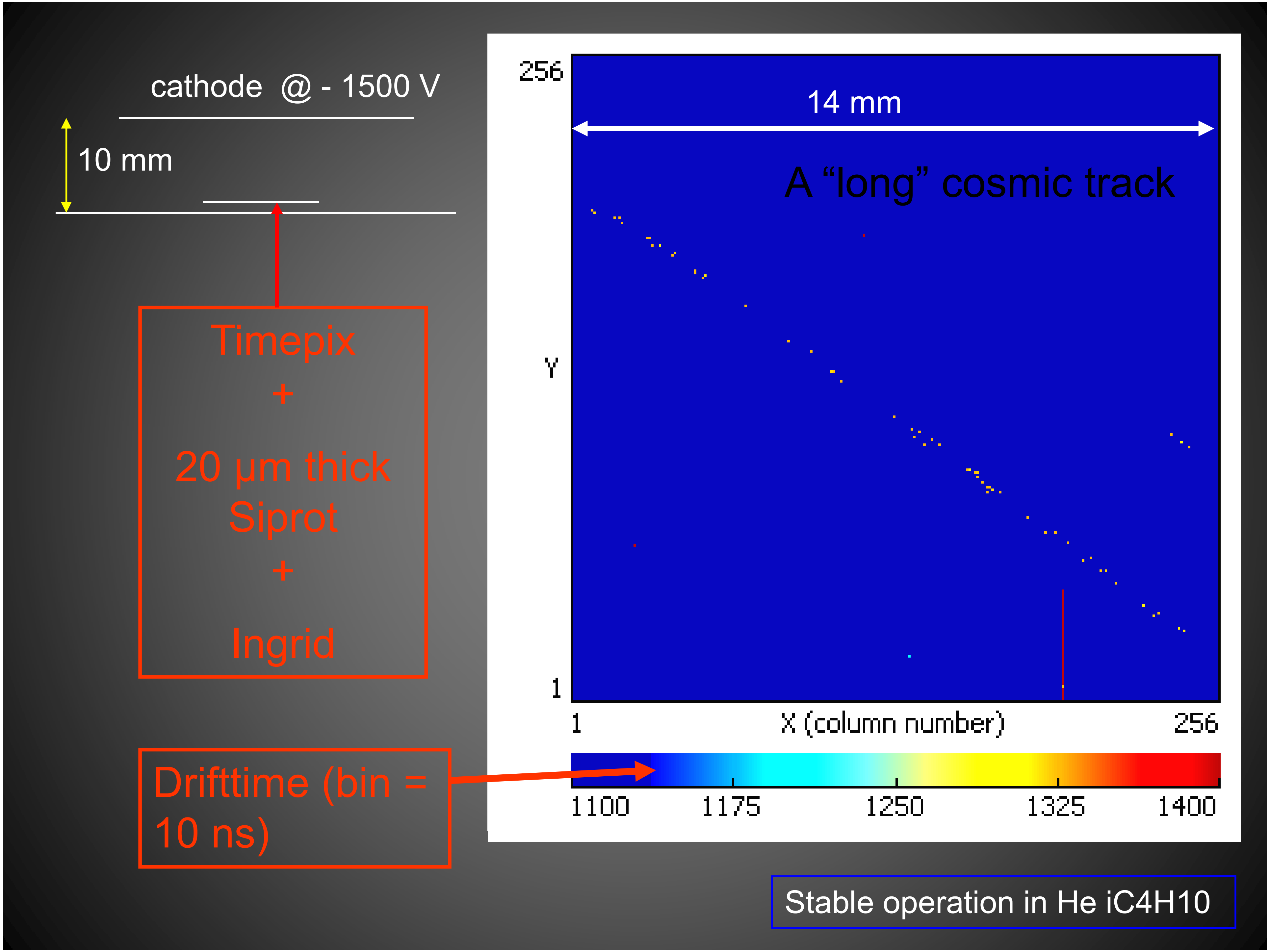


A “scratch” occurred during the construction of Ingrid;

Loose parts removed. Ingrid working!

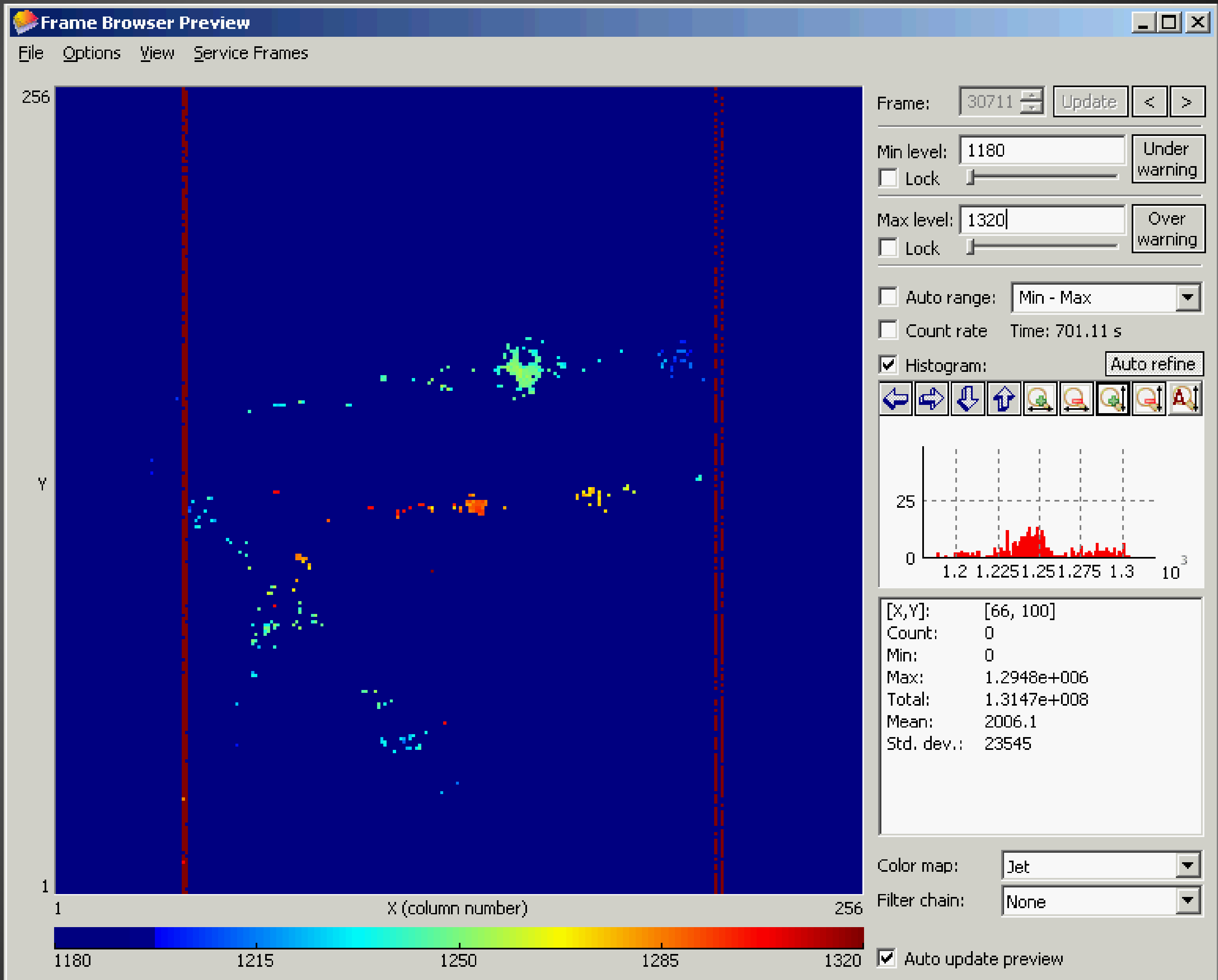
setup



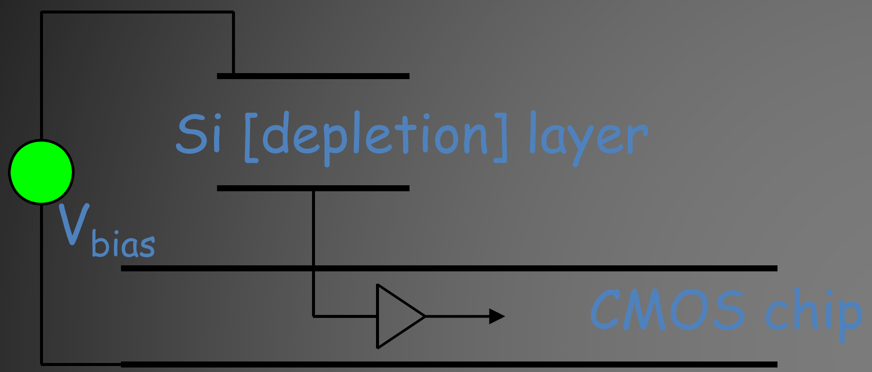

cathode @ - 1500 V
10 mm
Timepix
+
20 µm thick
Siprot
+
Ingrid
Drifttime (bin = 10 ns)
256
14 mm
A "long" cosmic track
Y
1
1
X (column number)
256
1100
1175
1250
1325
1400
Stable operation in He iC4H10

Cosmic rays in Argon

Time mode

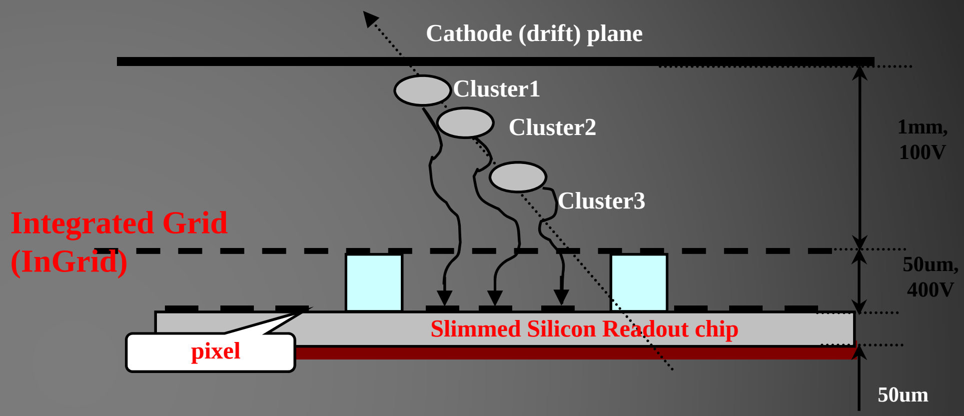


Si (vertex) track detector



- Si strip detectors
- Si pixel detectors
- MAPs
- CCDs

GOSSIP



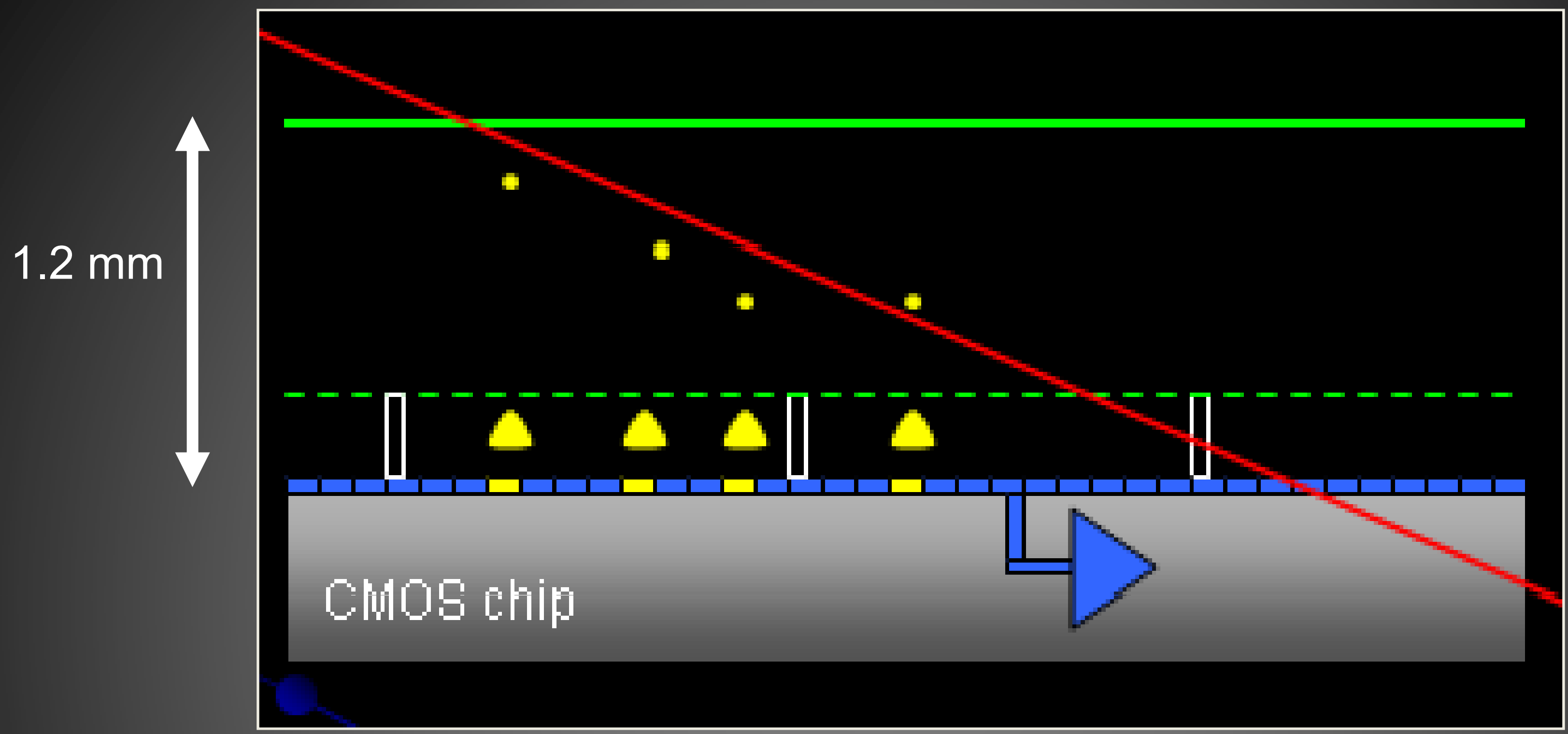
Gas: 1 mm as detection medium

99 % chance to have at least 1 e-

Gas amplification ~ 1000:

Single electron sensitive

All signals arrive within 20 ns



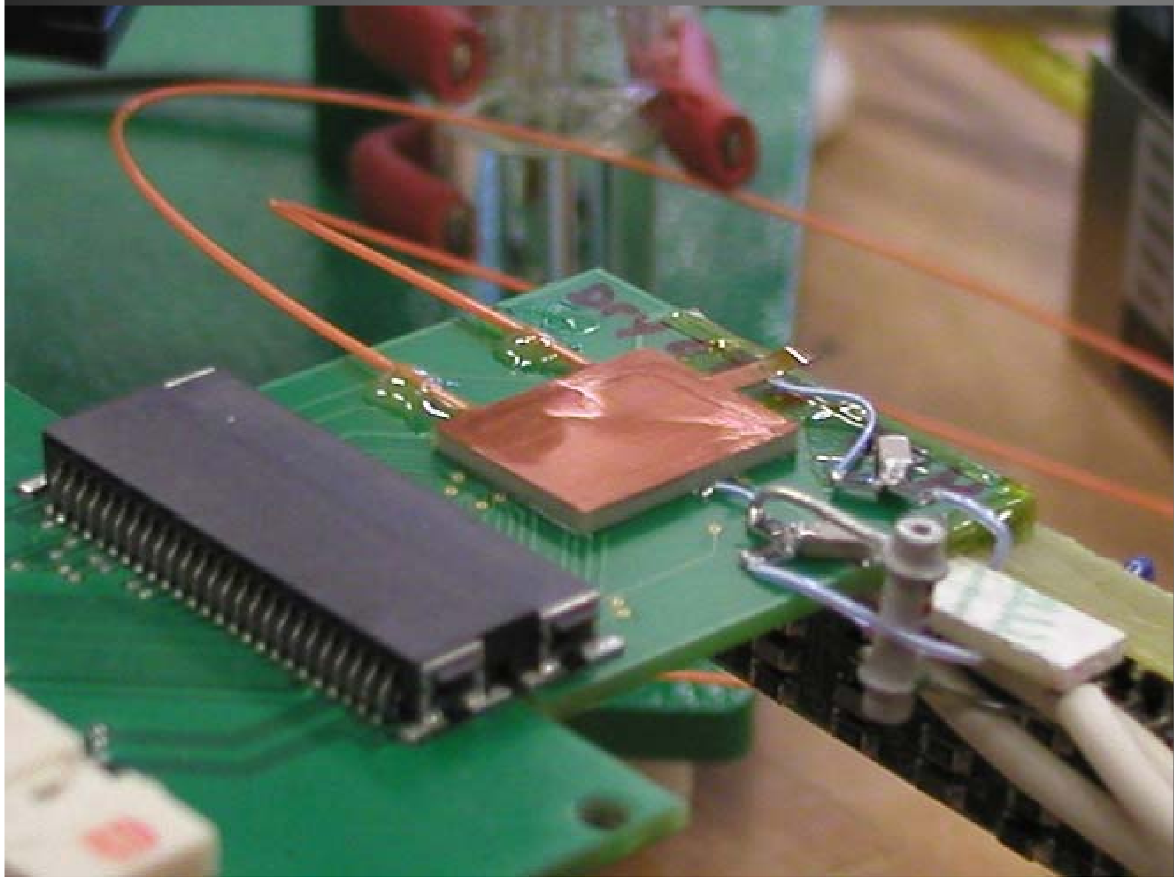
Gossip [Gas On Slimmed Silicon Pixels]
replacement of Si tracker

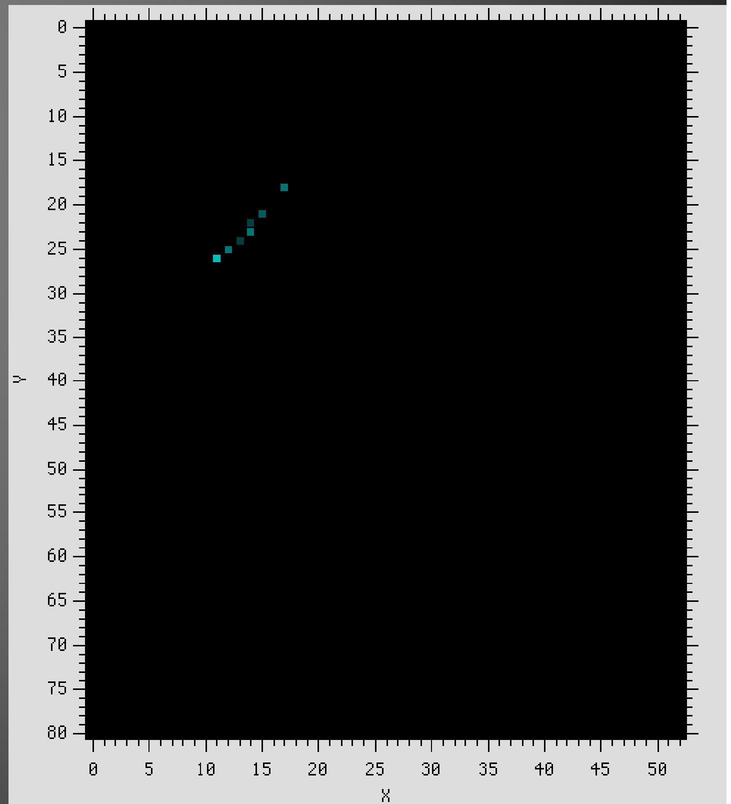
Essential: thin gas layer (1.2 mm)

GOSSIP-Brico: PSI-46 (CMS Pixel FE chip)

First prototype of GOSSIP on a PSI-46 (CMS Pixel FE chip)is working:

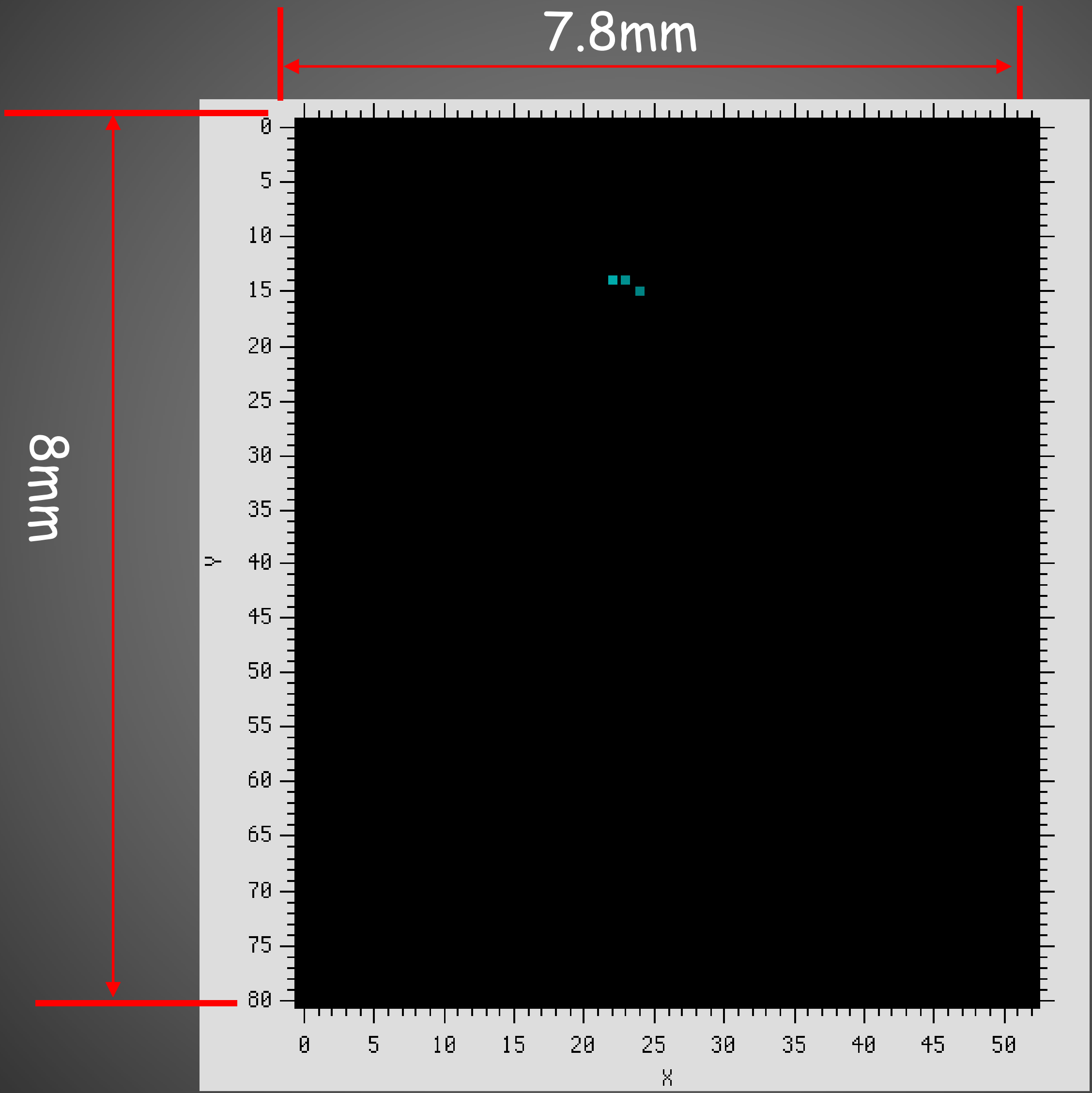
- 1.2 mm drift gap
- Grid signal used as trigger
- 30 µm layer of SiProt





We can see tracks!

(Frame # 17 is really great)



Animated GIF of 100 hits on the PSI46 brico, 30μm SiProt.
(if this does not animate, drop the picture into a web browser)

Tracking sensor material: gas versus Si

- primary electrons can simply be multiplied: gas amplification: low power

- gas can be exchanged: no radiation damage of sensor

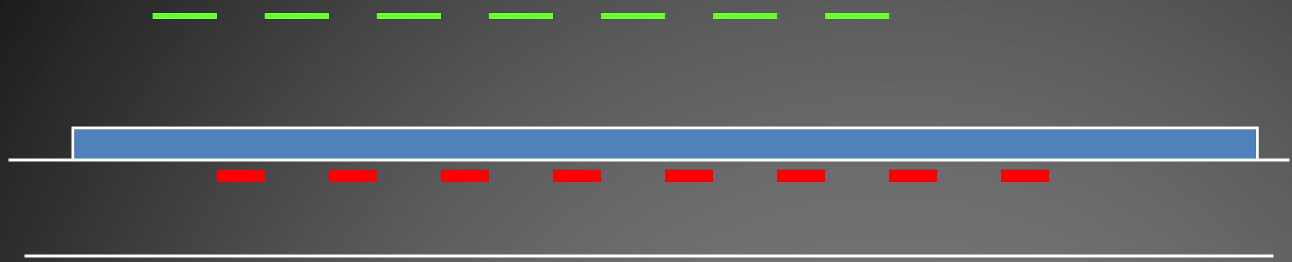
- no bias current: low power & simple FE circuits

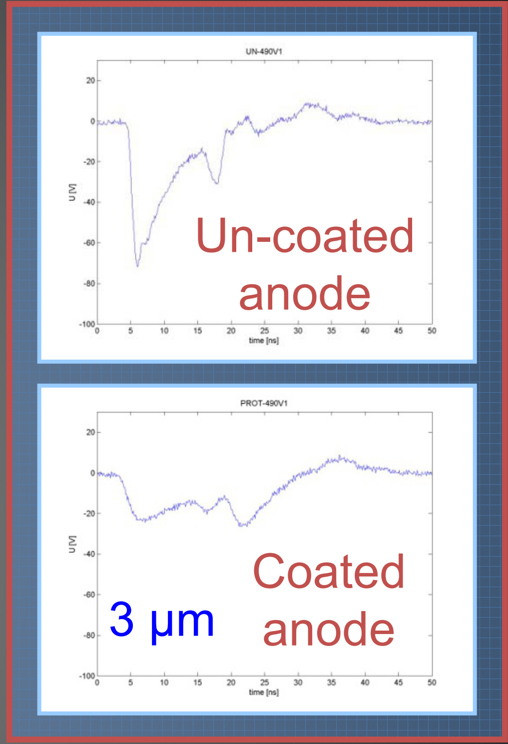
- it is light and cheap

- gas has a low ε_r: with small voxels the source capacity can be small (10 fF) allowing fast, low-noise, and low-power preamps

- no temperature requirements
- low sensitive for neutron and X-ray background [and can detect < 1 keV quanta!]
- δ-rays can be recognized
- [high ion & electron mobility: fast signals, high count rates are possible]

- discharges/sparks: readout system should be spark proof
- ageing: must be solved and must be understood / under control
- diffusion: limits max. drift length





SiProt protection against:

- hot spark plasma
- too large charge in pixel circuitry [principle of RPCs]
    - local reduction of E-field: quenching
    - widening discharge funnel: signal dilution
    - [increased distance of ‘influention’]

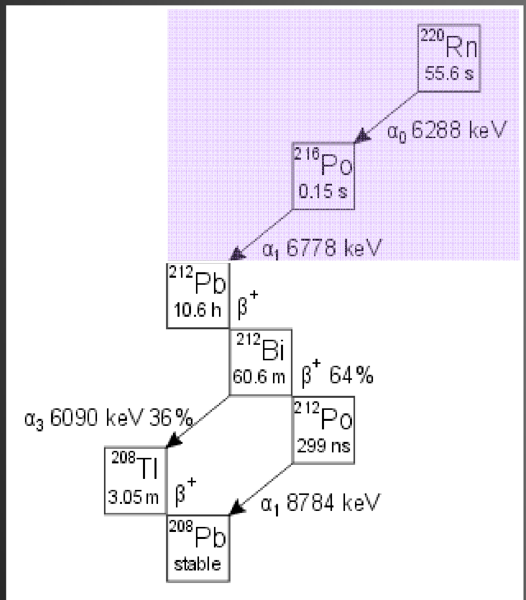
SiProt: a low T deposited hydrogenated amorphous silicon (aSi:H) layer

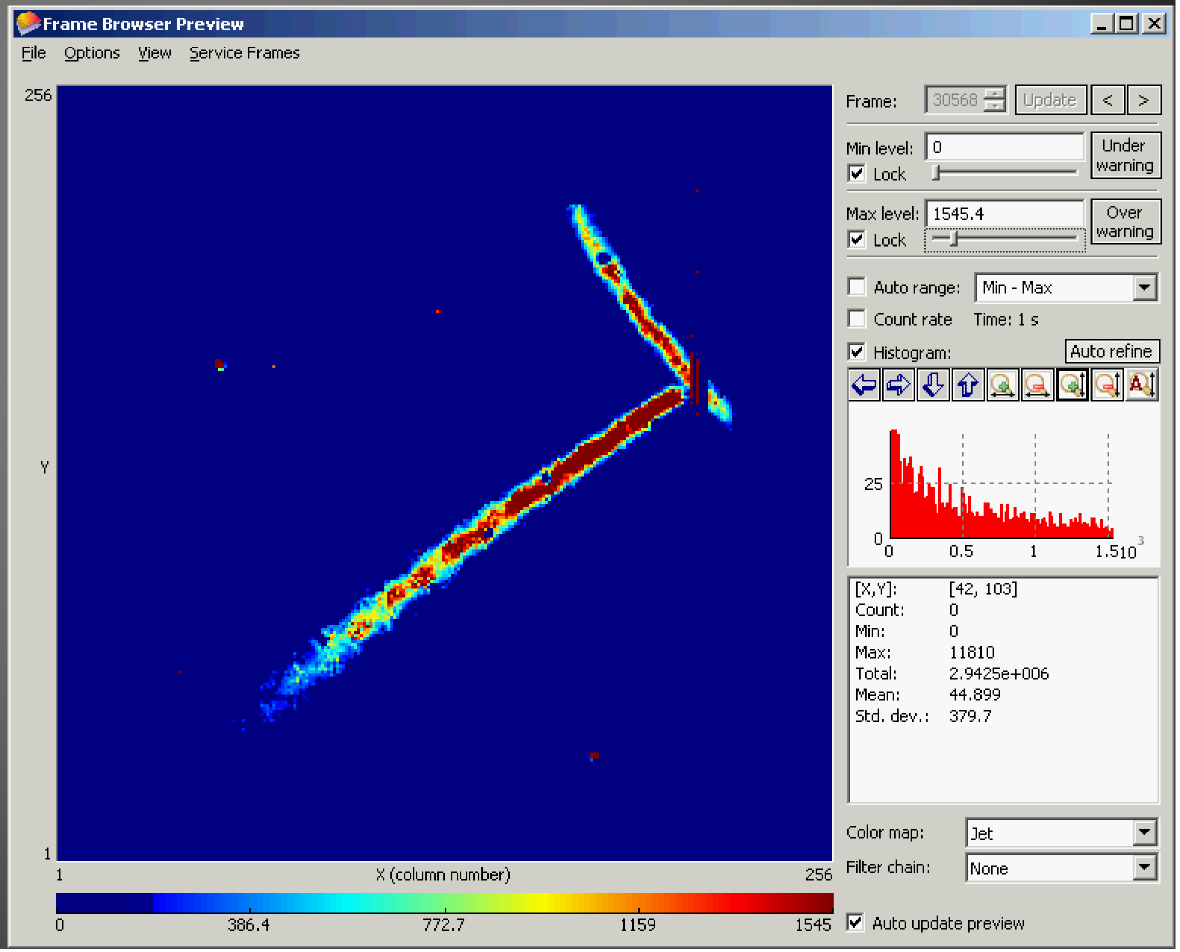
Up to 50 μm thick films, ~ 10^7 - 10^{11} Ω.cm

Final assessment: spark-proofness

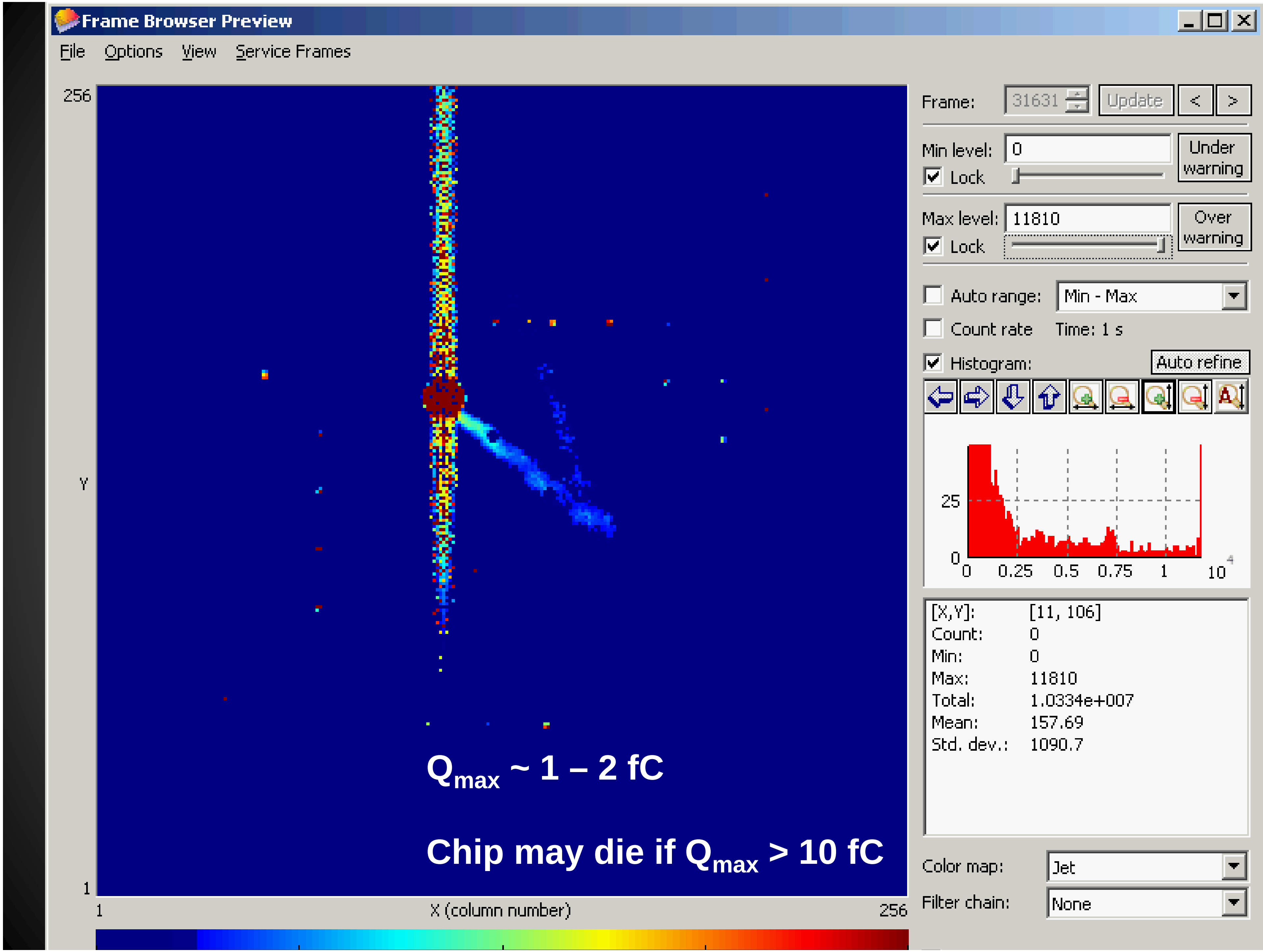
- Provoke discharges by introducing small amount of Thorium in the Ar gas [Ropelevski et al.]
  - Thorium decays to Radon 222 which emits 2 alphas of 6.3 & 6.8 MeV
  - Depose on average $2.5.10^5$ & $2.7.10^5$ e- in Ar/iC_4H_{10} 80/20 at -420 V on the grid, likely to trigger discharges

Charge mode





Since 1 week, some 5.10^4 alpha events recorded in 1% of which …



Q_{max} ~ 1 – 2 fC

Chip may die if Q_{max} > 10 fC

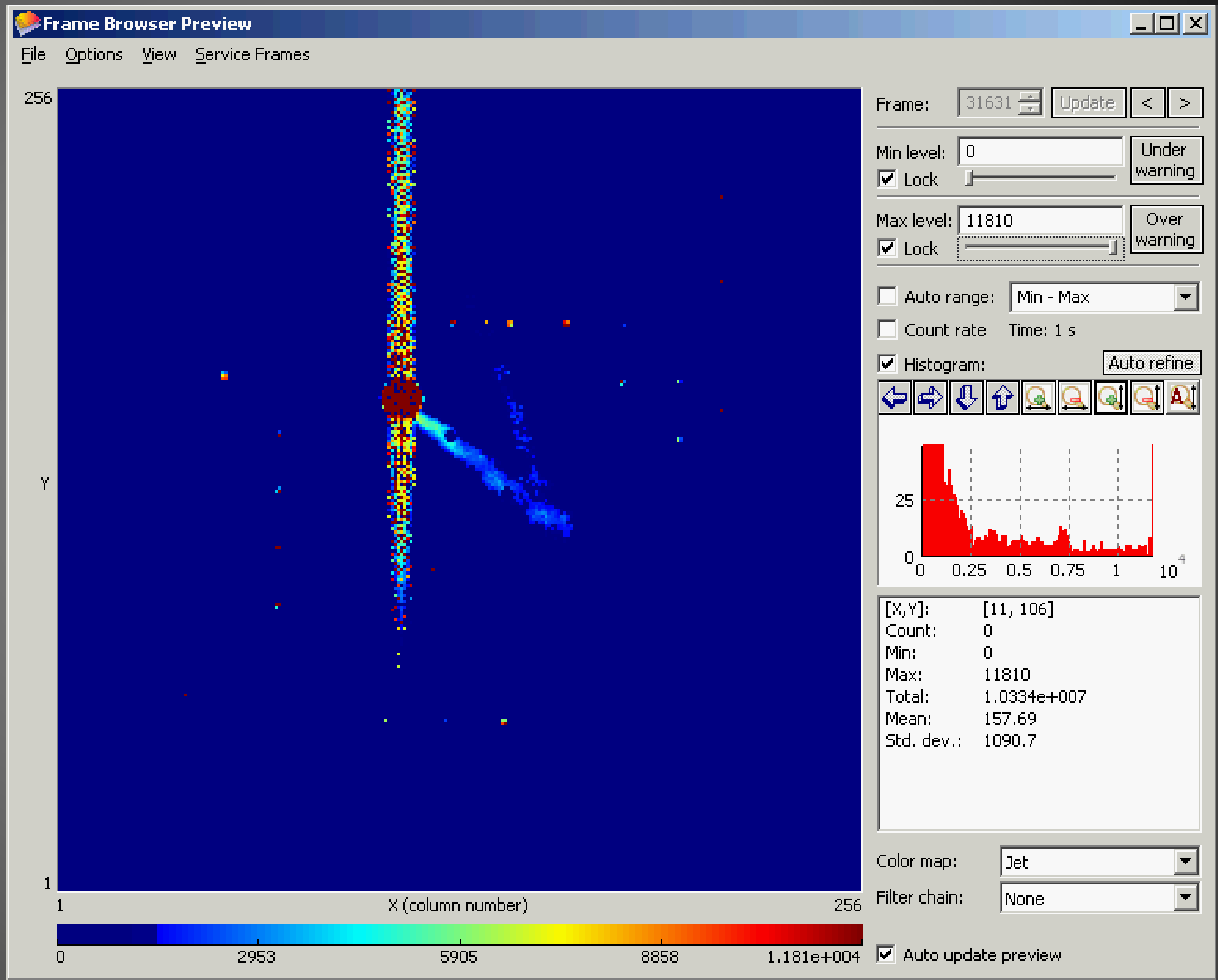
… discharges are observed !

For the 1st time: image of discharges are being recorded

Round-shaped pattern of some 100 overflow pixels

Perturbations in the concerned column pixels
- Threshold
- Power

Chip keeps working



July 2008: protection layer made of Si_3N_4 (Silicon Nitride), only 7 μm thick

$$3\ SiH_4 + 4\ NH_3 \rightarrow 3\ Si_3H_4 + 6\ H_2$$

Silicon Nitride is often applied as passivation layer:
top finish of chips.

With overdose of SiH_4:conductivity: high resistively bulk material

Favoured material for bearings in turbo chargers, jet engines

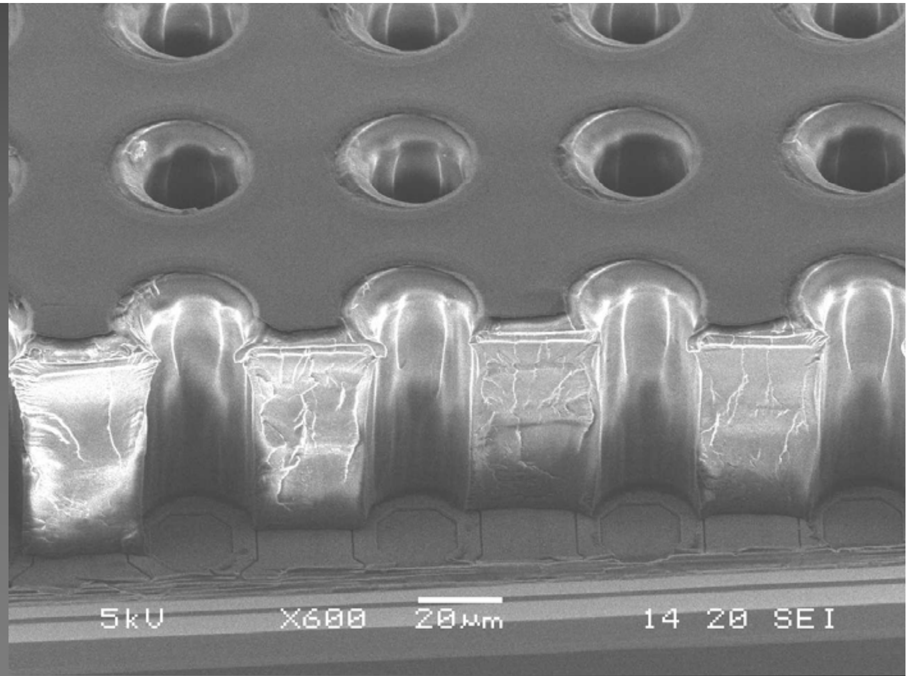
The application of SiNProt and InGrid on CMOS chip is likely
to become a standard, low cost procedure by industry
[compare bump-bonding of Si sensors & processing Si sensors]

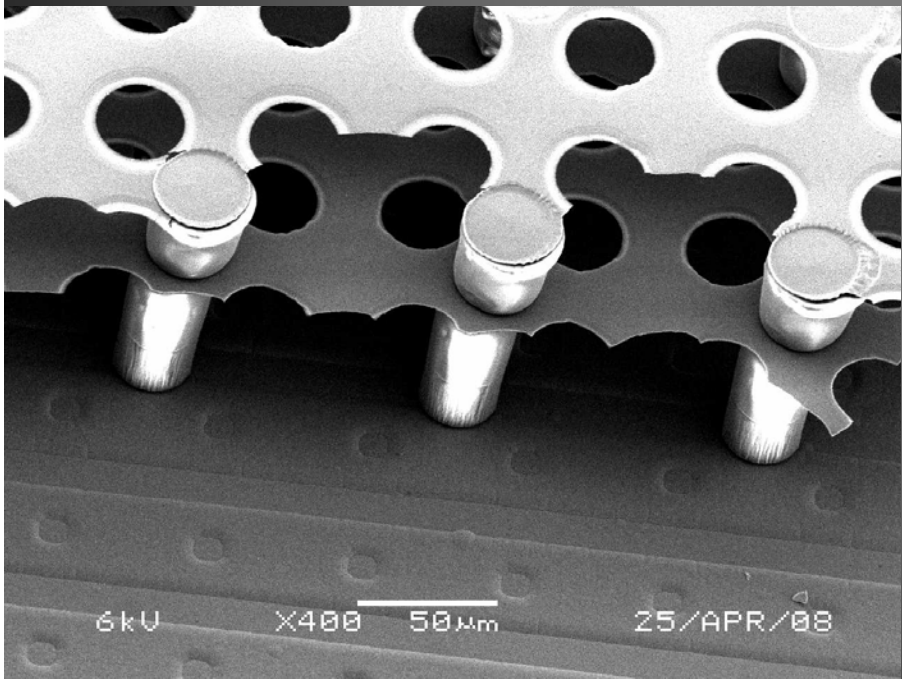
New InGrid developments:

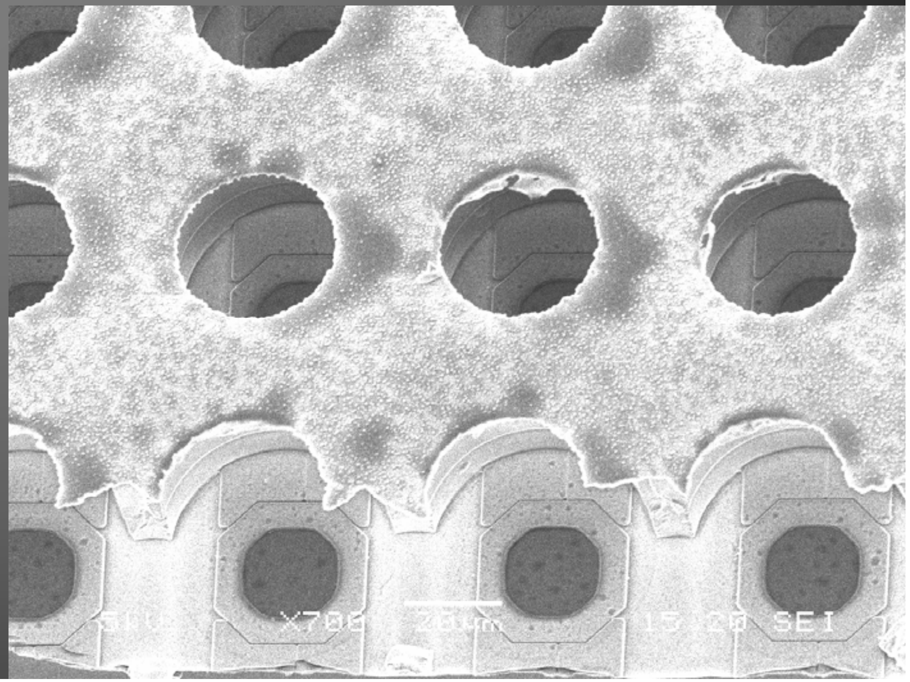
InGrid production being transferred to IZM-Fraunhofer Berlin

TwinGrid

GemGrid







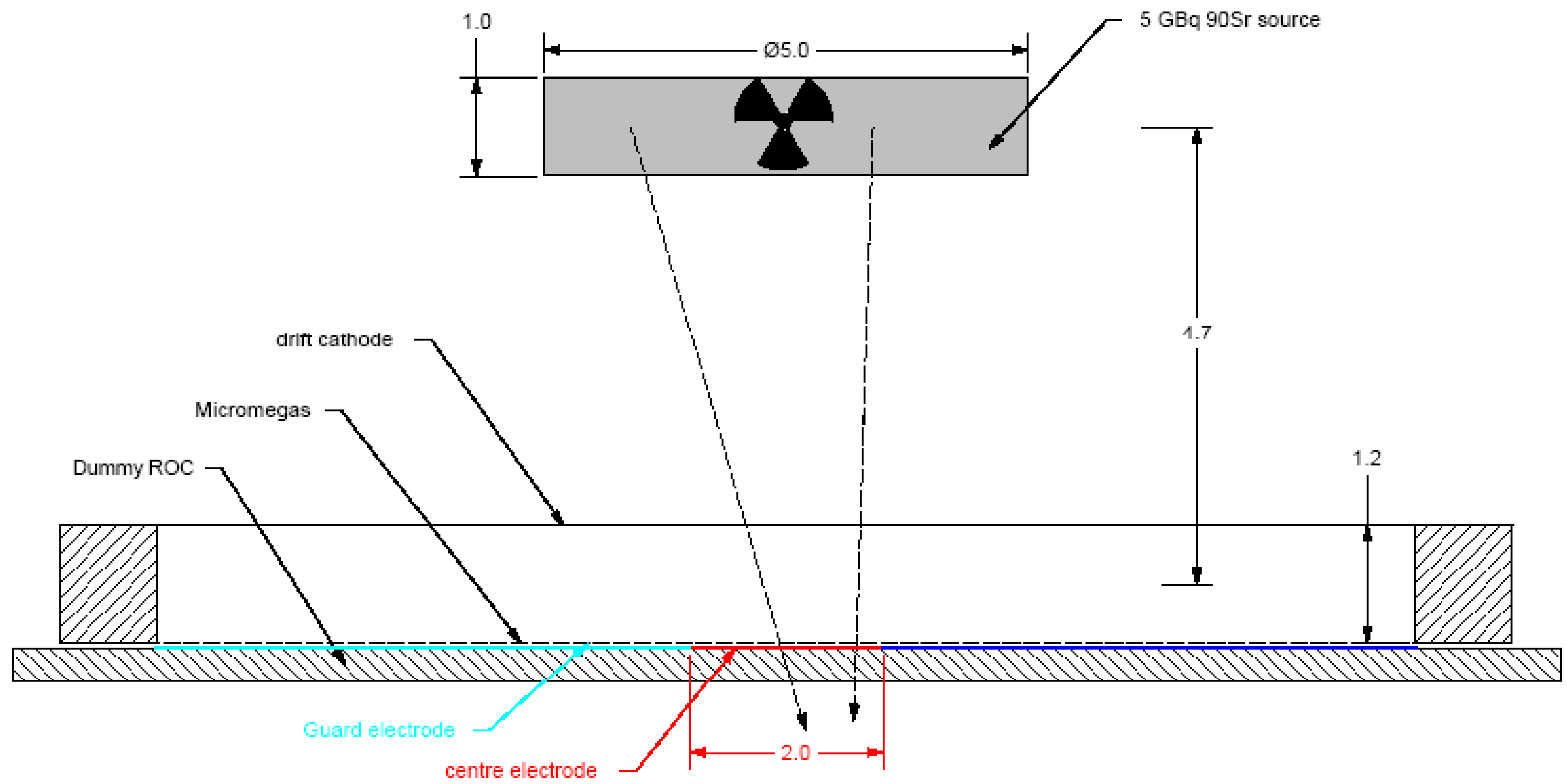
Ageing

Radiation damage of CMOS pixel chip is relevant
- common for all tracking detectors
- believed to widthstand ATLAS Upgrade Dose in 90 nm technology

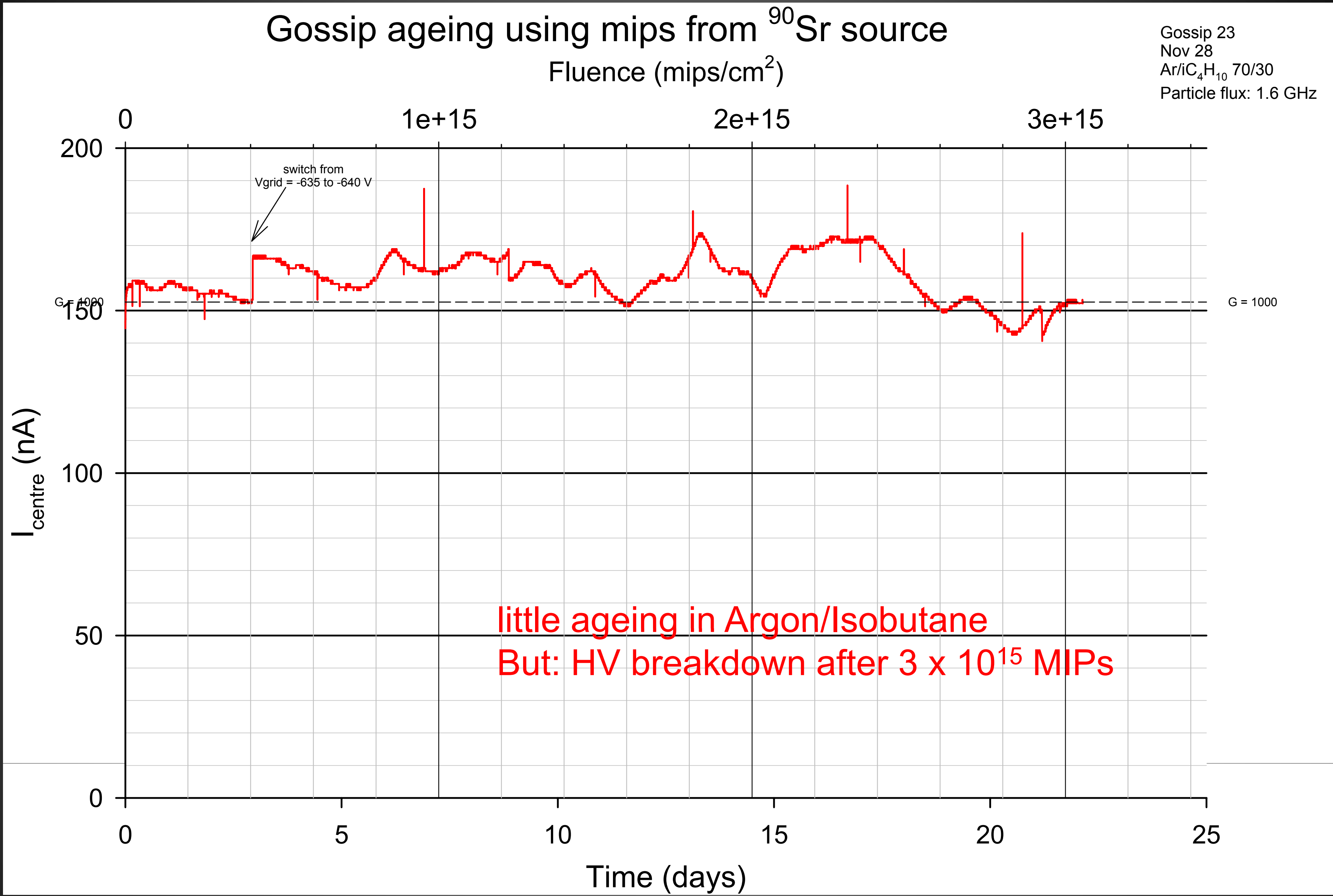
Radiation damage of sensor:
not relevant for Gossip sensor since this is gas being exchanged

Typical for gaseous detectors: the deposit of an (insulating) polymer on the electrodes of a detector. Decrease of signal amplitude

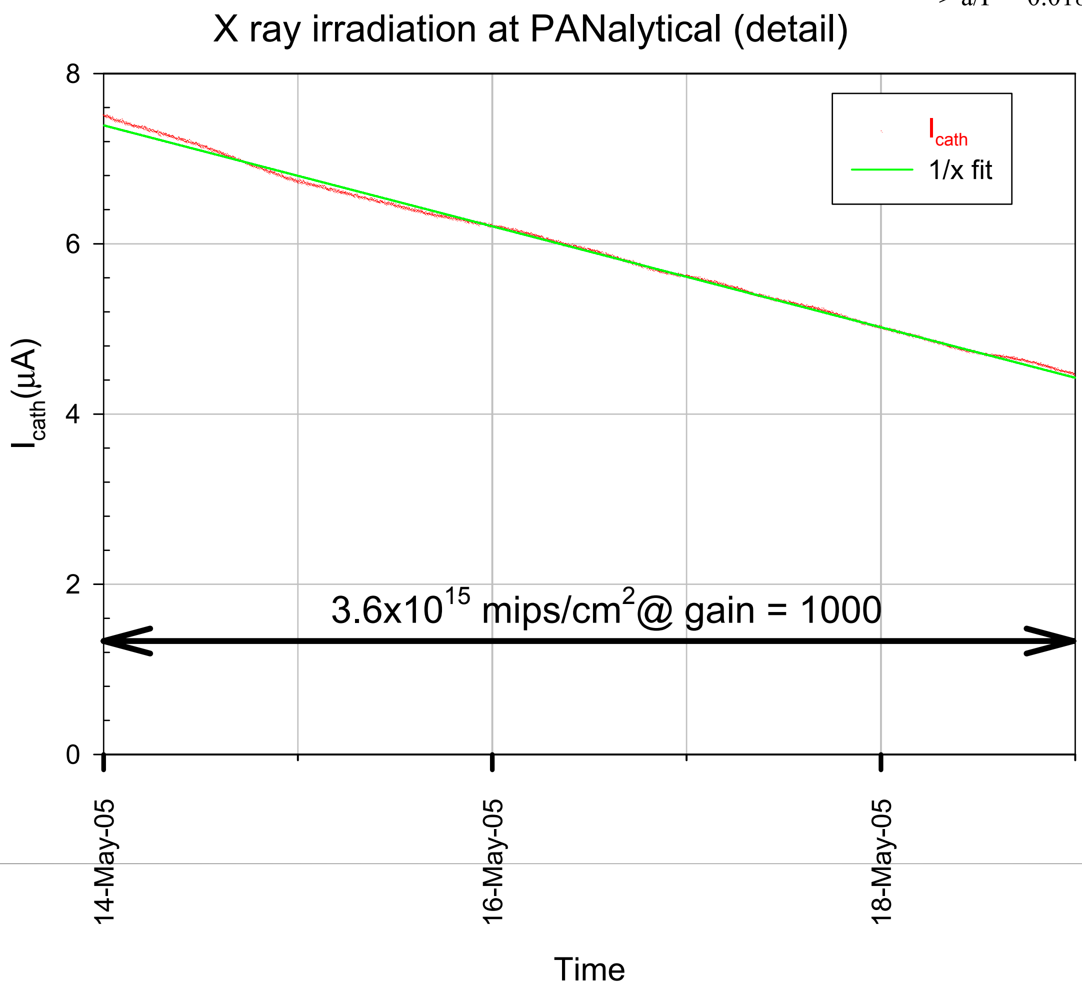
Little ageing expected:
- little primary ionisation (~ 10 e-/track)
- low gas gain (500 – 1000)
- large anode surface (compare pixel anode plane with surface of thin wire)
- E-field at flat anode ~3 lower than E-field at anode wire



set up ageing test

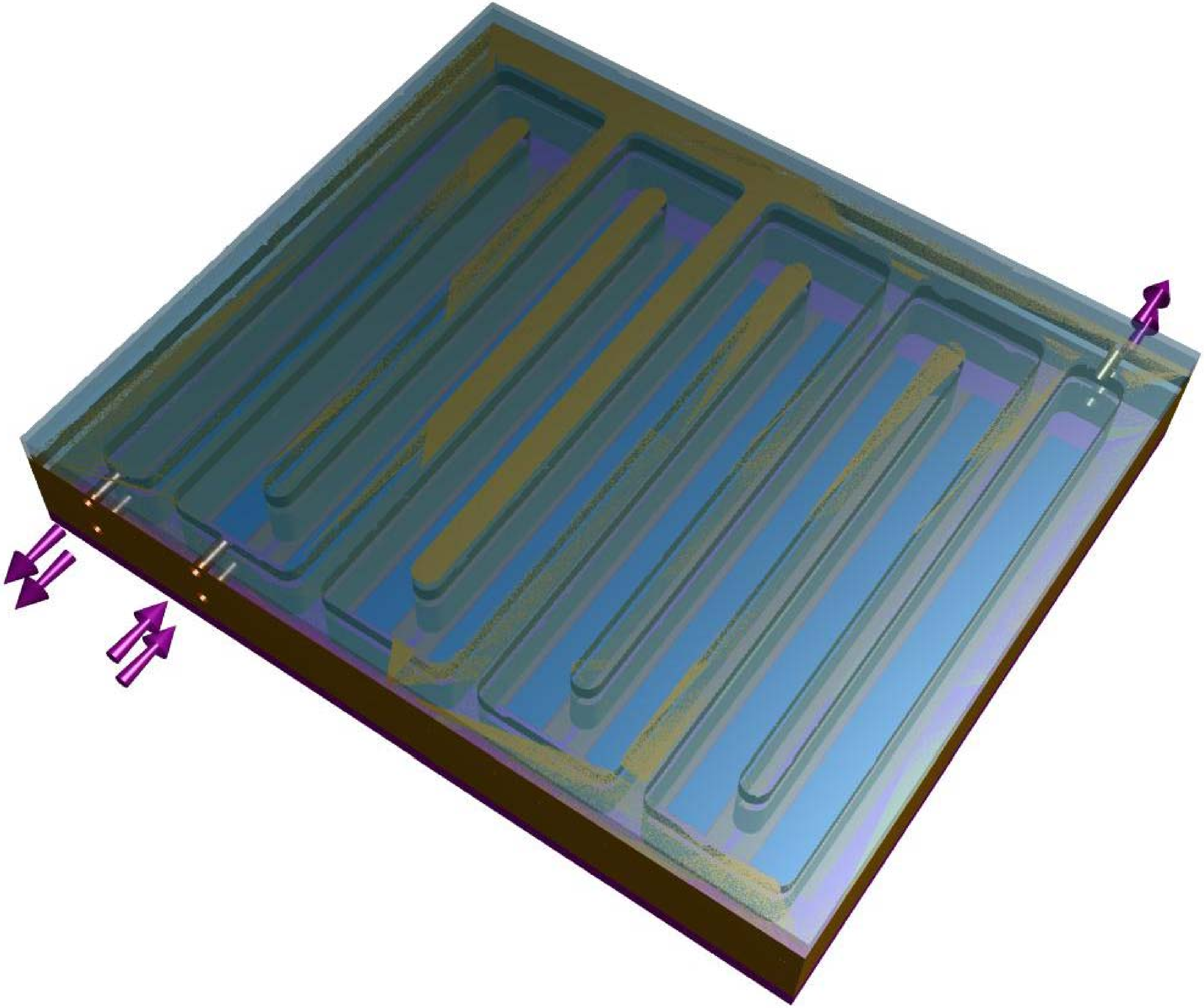

Gossip ageing using mips from 90Sr source
Fluence (mips/cm2)
Gossip 23
Nov 28
Ar/iC4H10 70/30
Particle flux: 1.6 GHz
0
1e+15
2e+15
3e+15
200
150
100
50
0
switch from
Vgrid = -635 to -640 V
G = 1000
Icentre (nA)
0
5
10
15
20
25
Time (days)
little ageing in Argon/Isobutane
But: HV breakdown after 3 x 1015 MIPs

Linear fit
$I = I^0 + a.t$
$a = -0.5932$
$\Rightarrow a/I^2 = 0.0183$

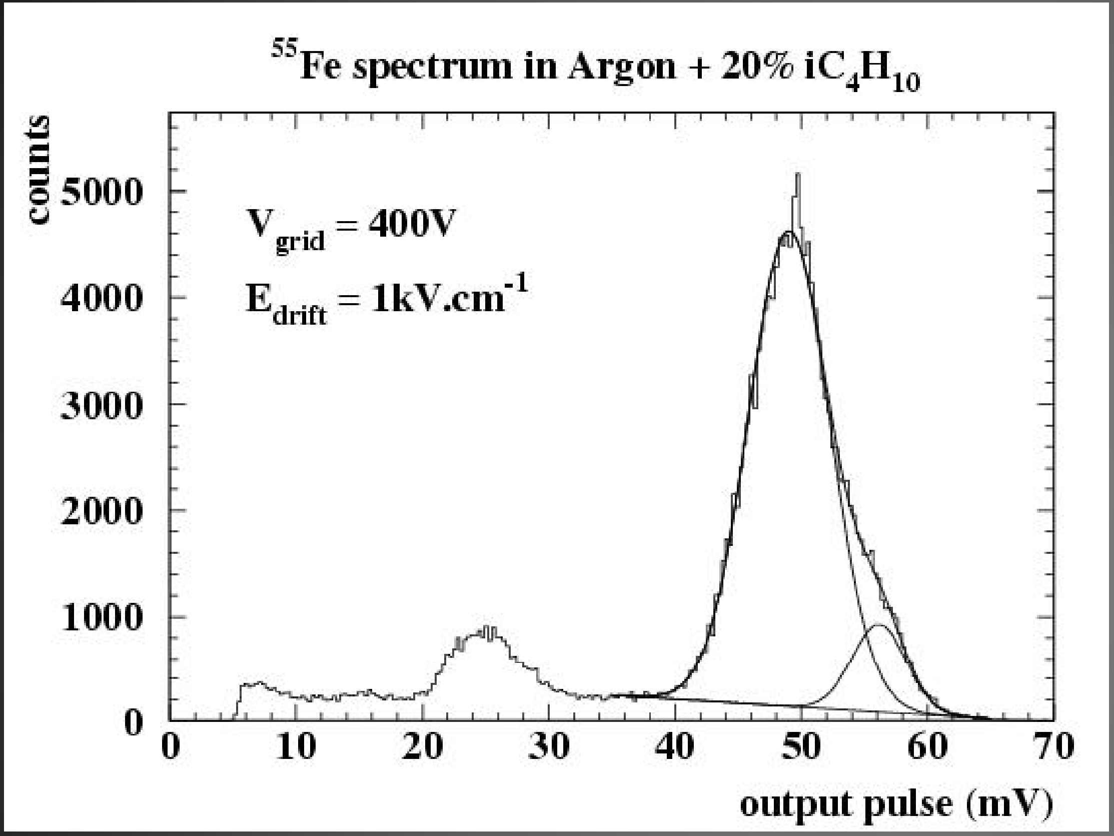


av current = 5.9 µA
=> total charge deposited
= 5.9*3600*24*4
= 2.55 C
surface 0.49 cm^2
=> 5.2 C/cm^2
assume: drift distance 1 mm
Ar/CH4 having $9e^-/mm$
=> 1 mip = $9*1000*1.6*10^{-19}$
= $1.44\ 10^{-15}$C
deposited charge corresponds to
$3.6\ 10^{15}$ mips/cm^2

gas: standard Ar/Methane 90/10. Deposit containing C found on anode



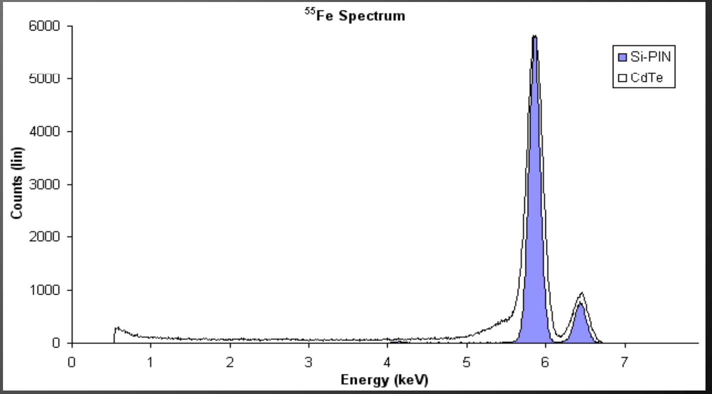
Energy resolution in Argon IsoC_4H_{10} 80/20



- Observation of two lines:
  - K_α @ 5.9 keV
  - K_β @ 6.4 keV
- FWHM of the K_α distribution
  - 16.7 %
- Gain fluctuations
  - < 5%

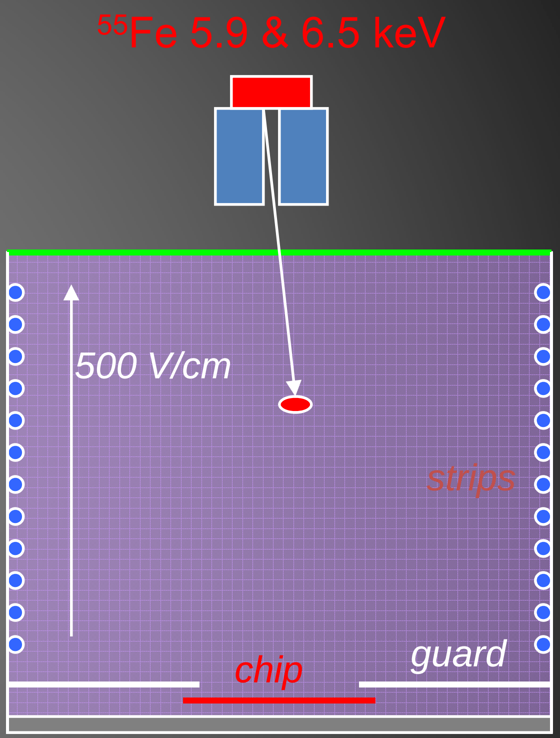
Very good energy resolution:

Very precise dimensions d < 0.1 μm



Demo: the digital TPC

- Gas chamber
  - Timepix chip
    15 µm SiProt + 50 µm InGrid
  - 10 cm drift gap
  - Cathode strips and Guard electrode
  - Ar 5 % iC_4H_{10}
- 55Fe source placed on top
  - Collimated to 2 mm Ø beam
  - Difficult to align precisely
- Ideally, gain & threshold homogeneous
  - Pixel to pixel threshold variations
    Threshold equalization provides uniform response
  - Gain homogeneity should be OK thanks to:
    Amplification gap constant over the chip (InGrid)
    Amplification gap close to optimum
- Imperative: have enough diffusion to perform counting
  - Long drift length, look at escape peak
  - However: SiProt layer induces charge on neighboring pixels

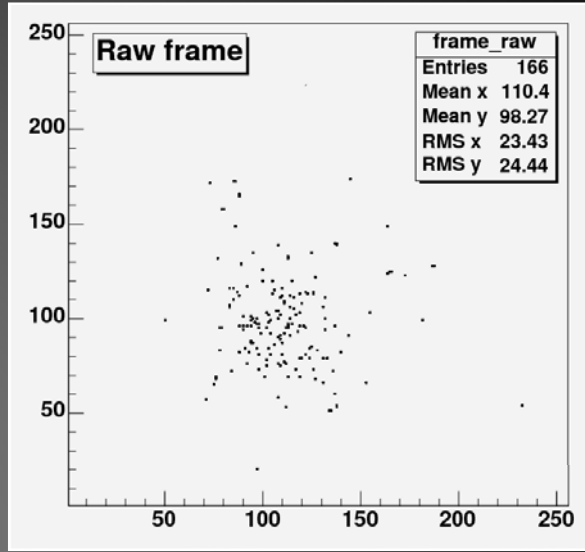


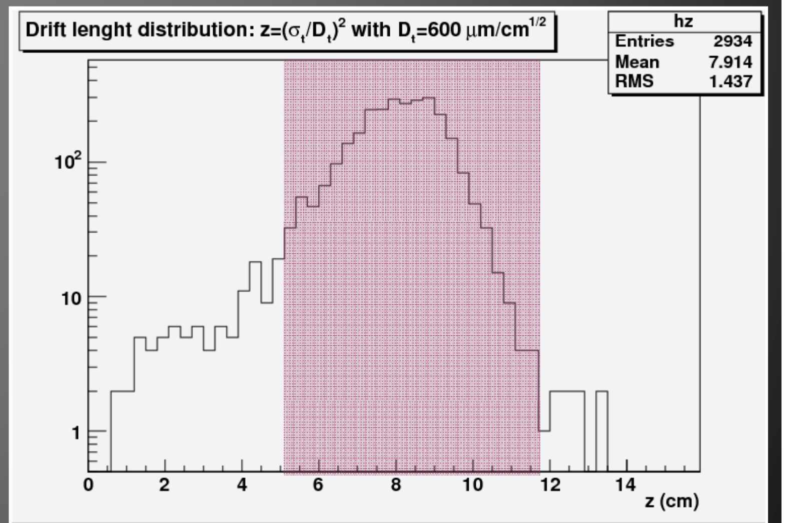
Event selection

- Suppress noise hits
  - Operate chip in TIME mode
    10 µs active time
    count clock pulses of 10 ns
  - Cut hits $4\sigma_t$ away from the mean time
  - Cut hits $4\sigma_{x,y}$ away from the mean x,y

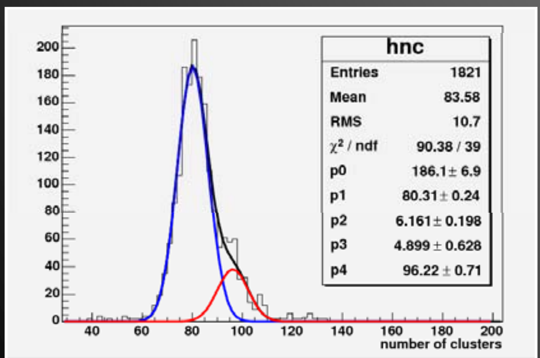
- Select large diffusion events
  - Measure the number of clusters as a function of spread (σ_t^2) for increasing grid voltages

- Effective number of electron from double Gaussian fit

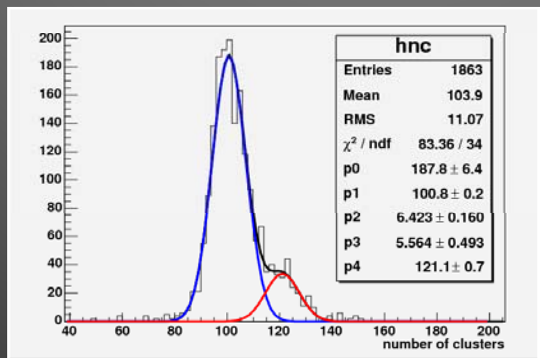




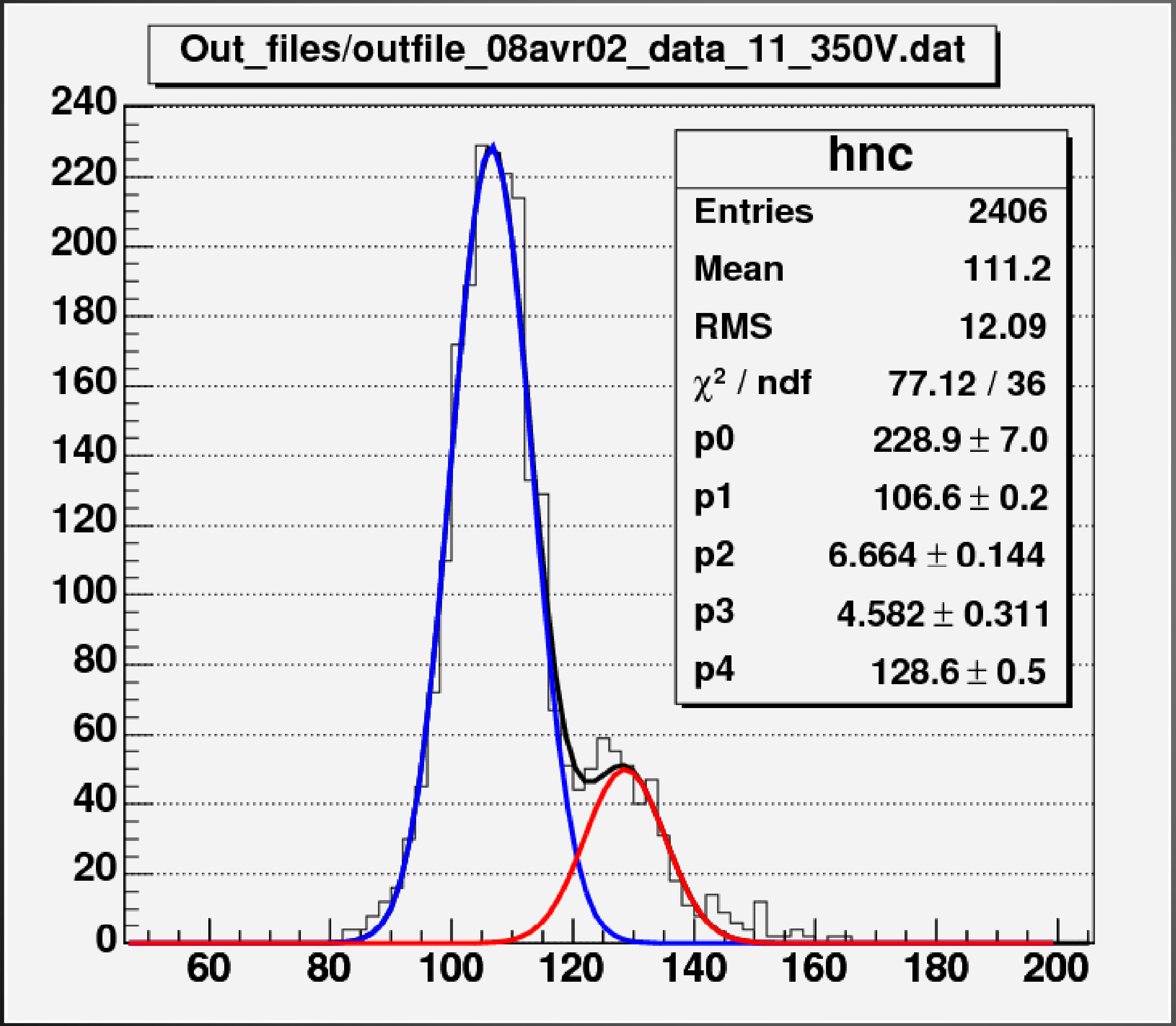
320 V



340 V



At 350V…^{55}Fe escape peak!!



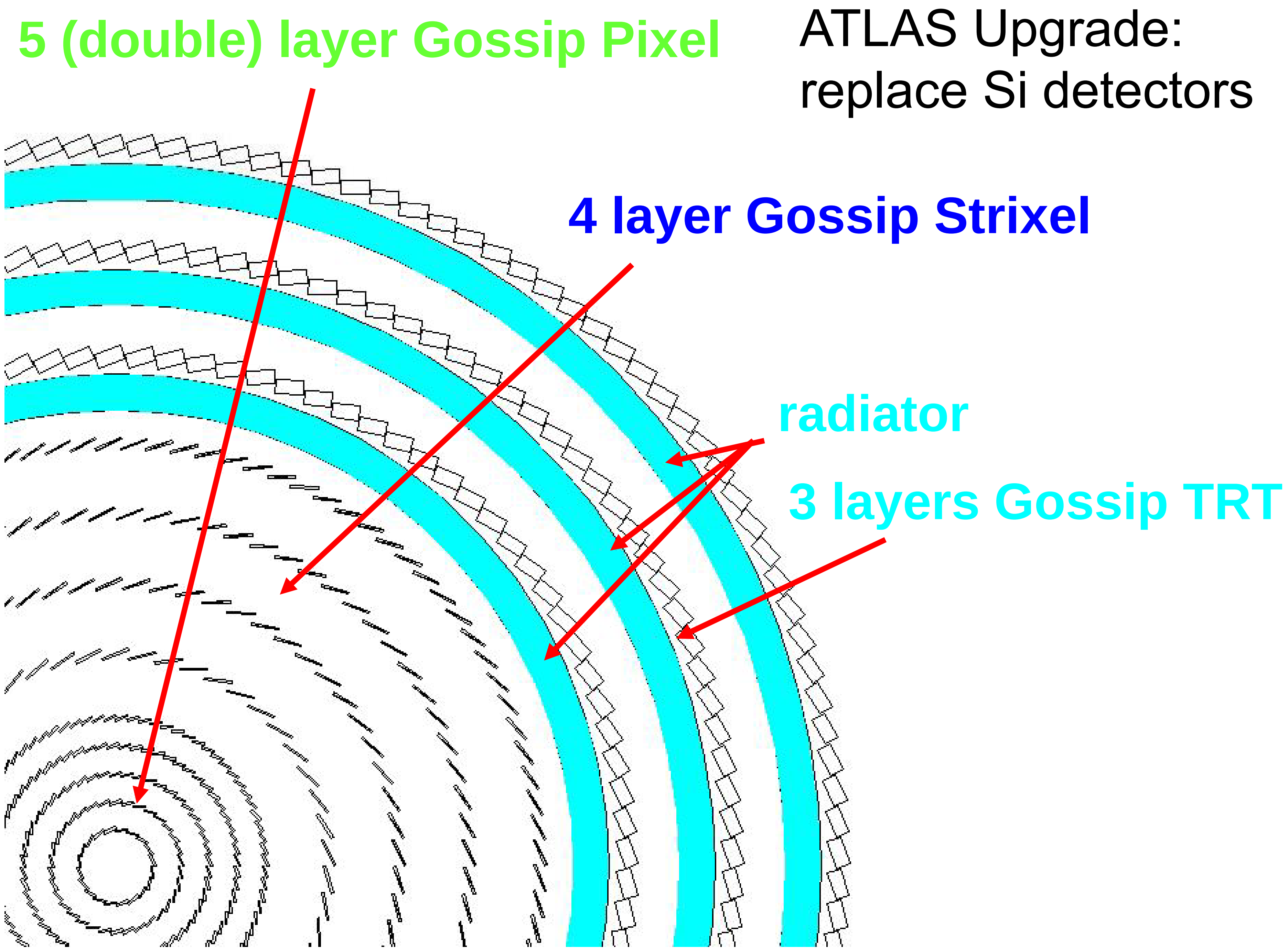
$RMS_t = 6.25\ \%$

$\eta = 0.93$

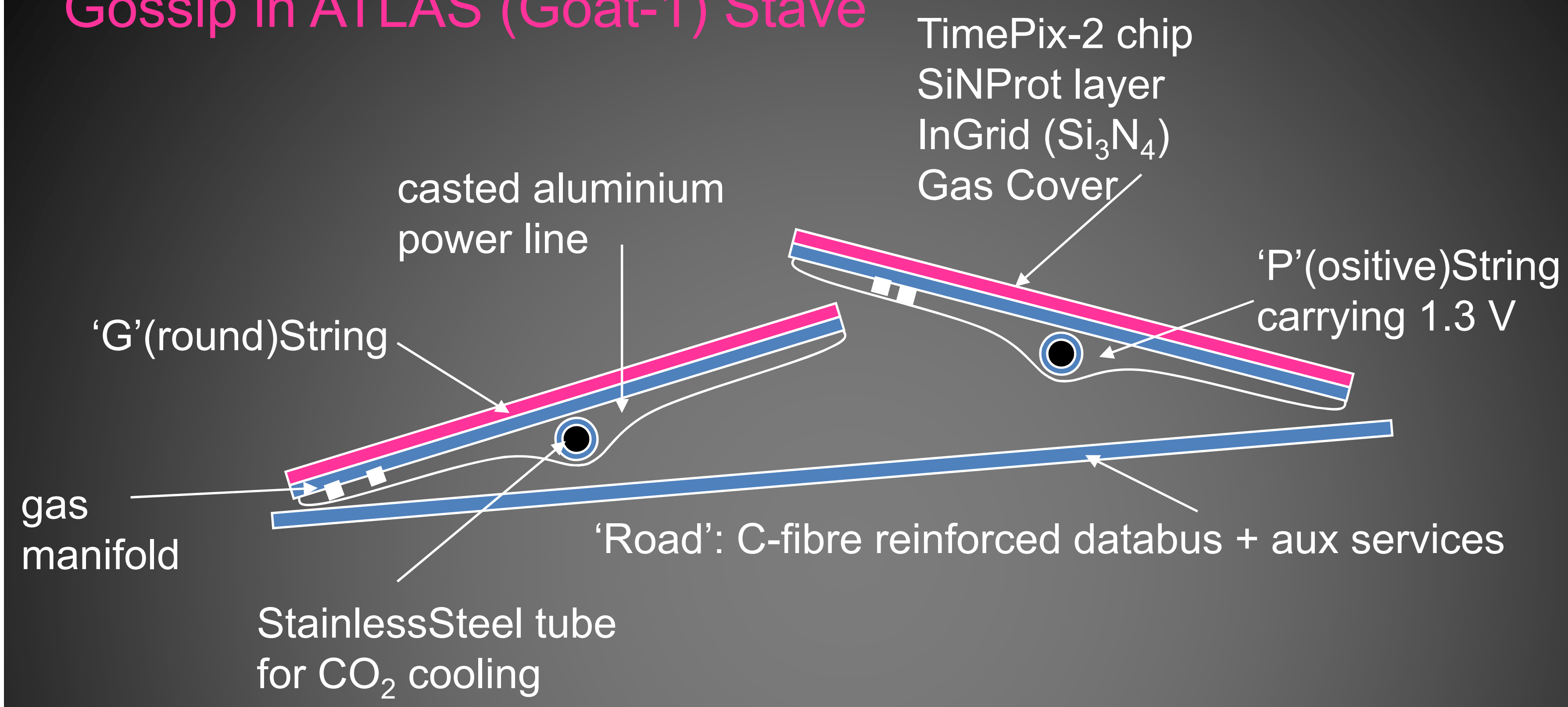
$RMS_\eta = 2.56\ \%$

$RMS_p = 5.70\ \%$

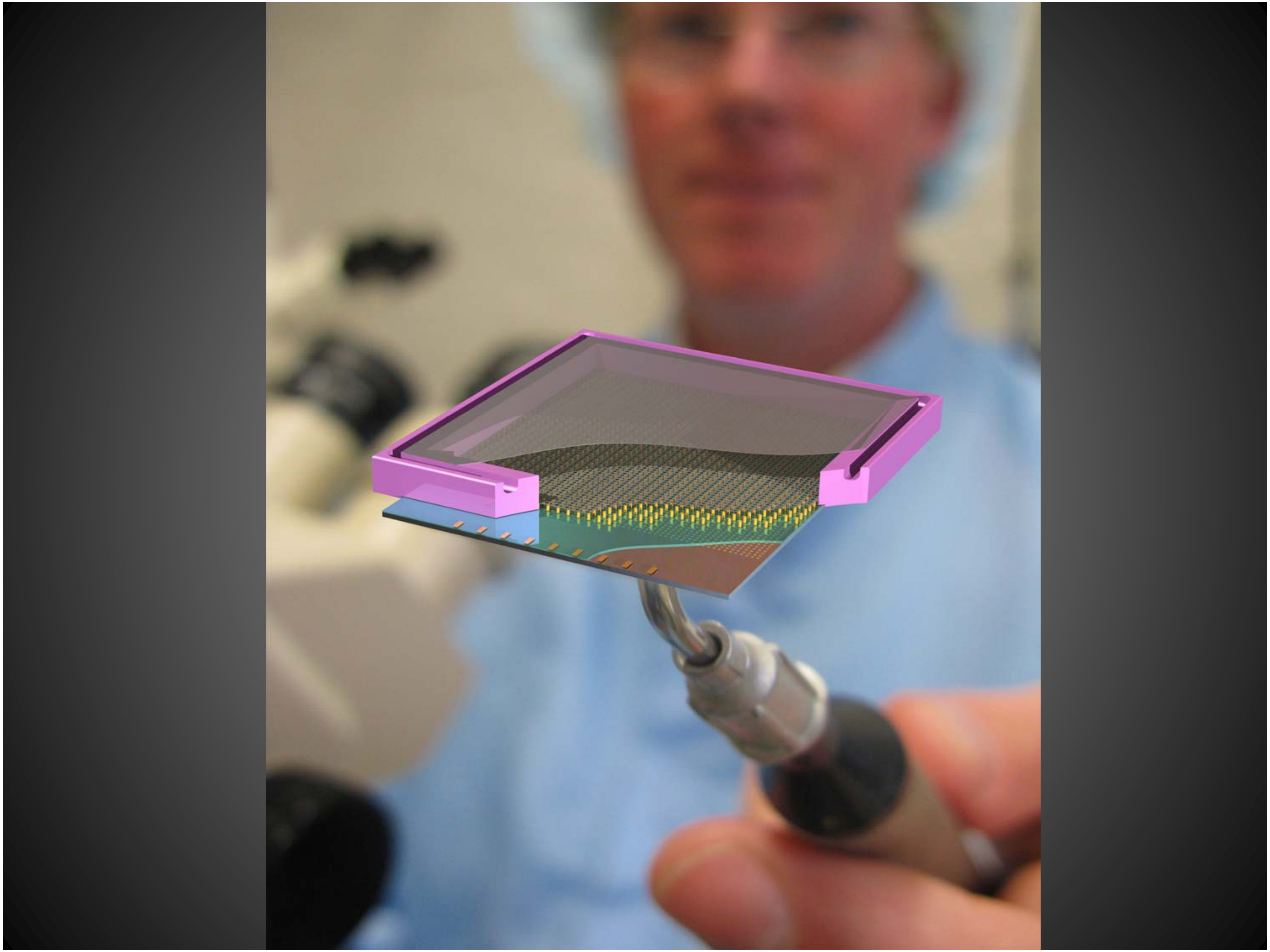
$F = 0.35$


5 (double) layer Gossip Pixel
ATLAS Upgrade:
replace Si detectors
4 layer Gossip Strixel
radiator
3 layers Gossip TRT

Gossip in ATLAS (Goat-1) Stave

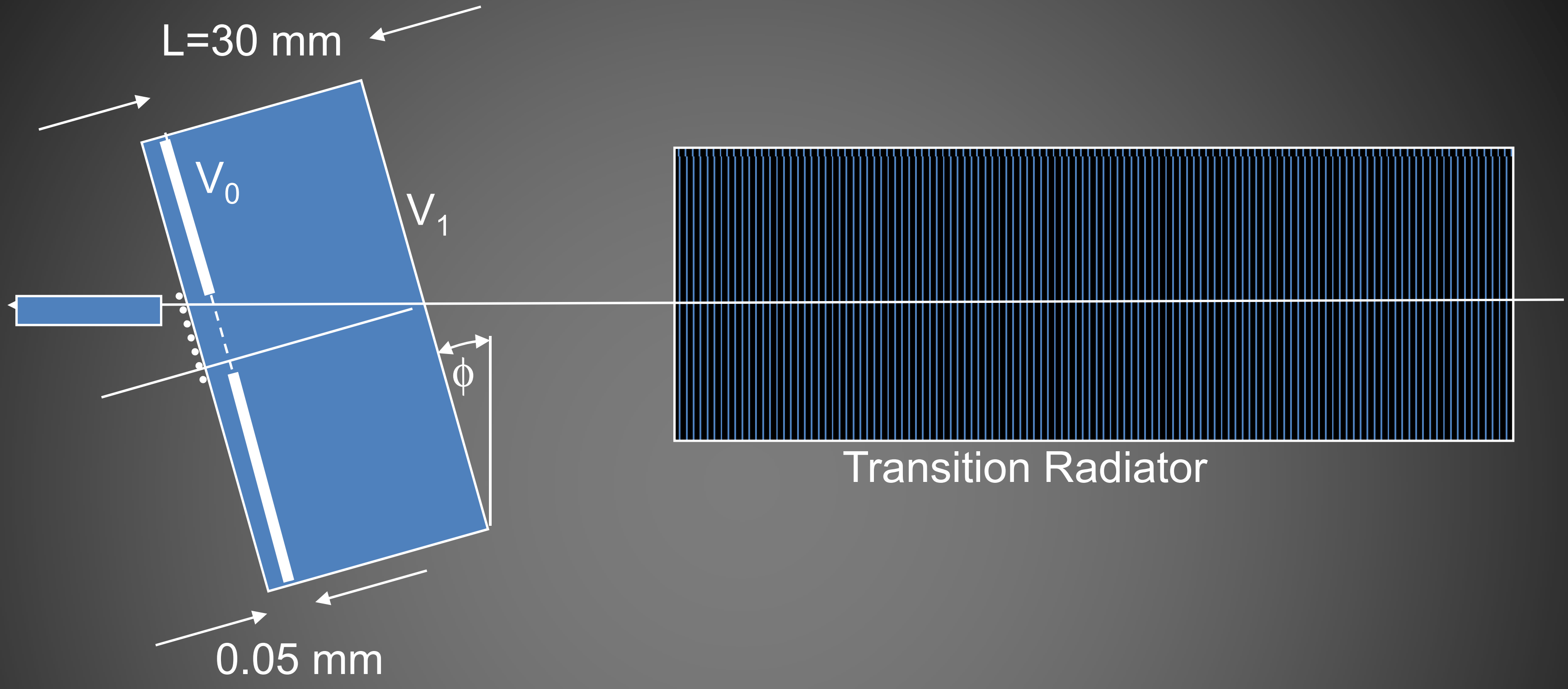


Stiff, light Stave formed by G-string, P-string, Road triangle



Testbeam Nov 5 – 12, 2007

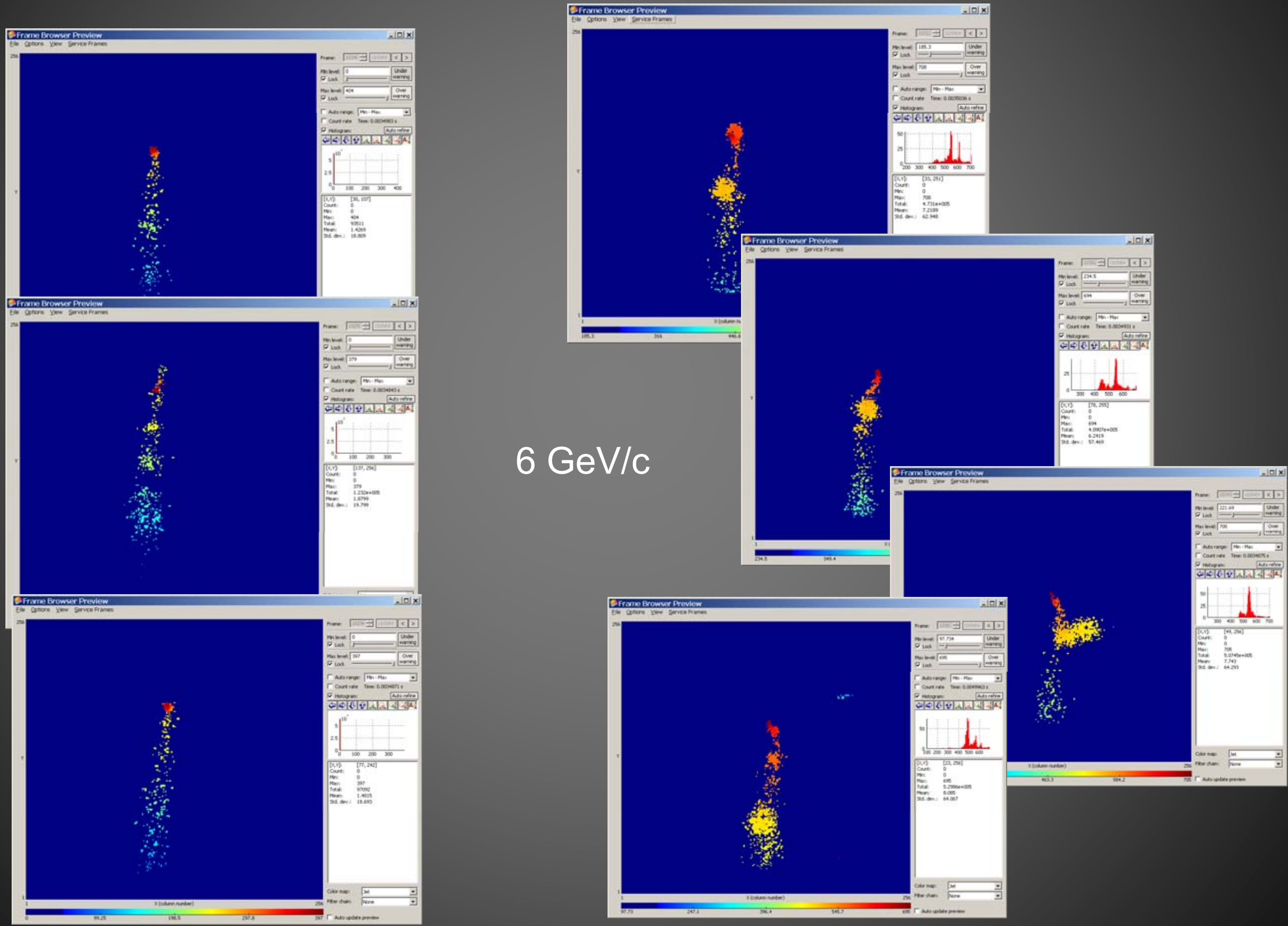
PS/T9: electrons and pions, 1 – 15 GeV/c



Anatoli Romaniouk, Serguei Morozov, Serguei Konovalov
Martin Fransen, Fred Hartjes, Max Chefdeville, Victor Blanco Carballo

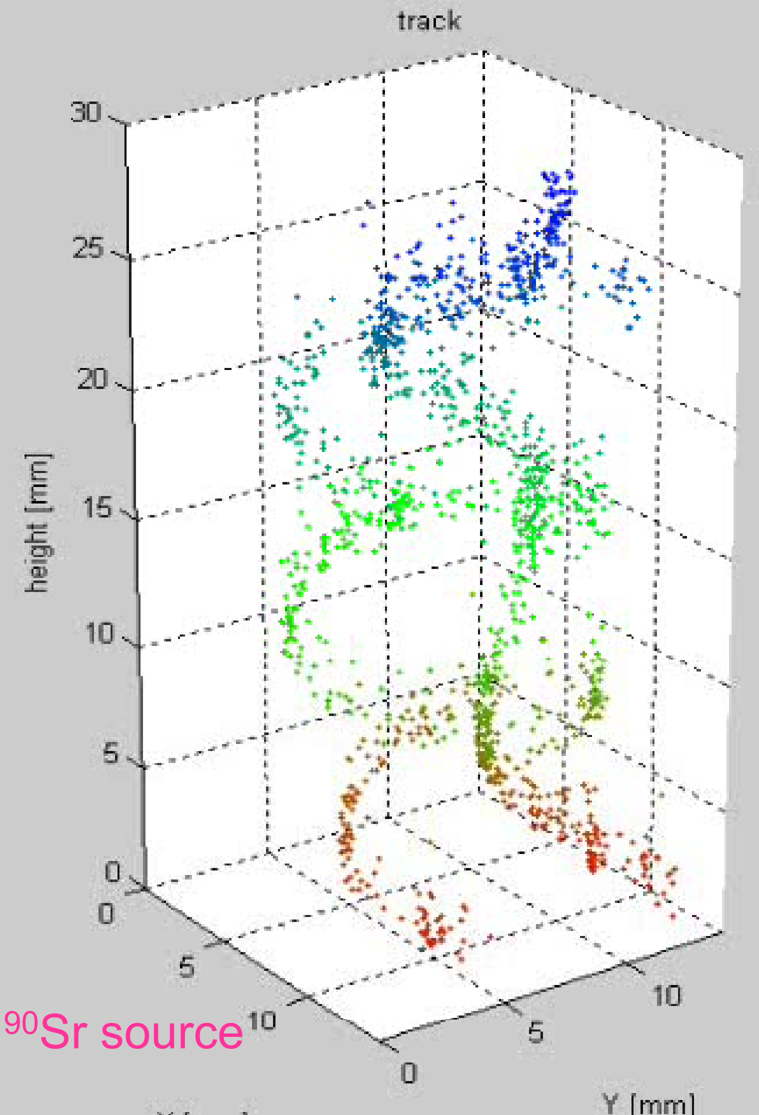
Particle Identification

Samples pions (left) and electrons (right)



6 GeV/c

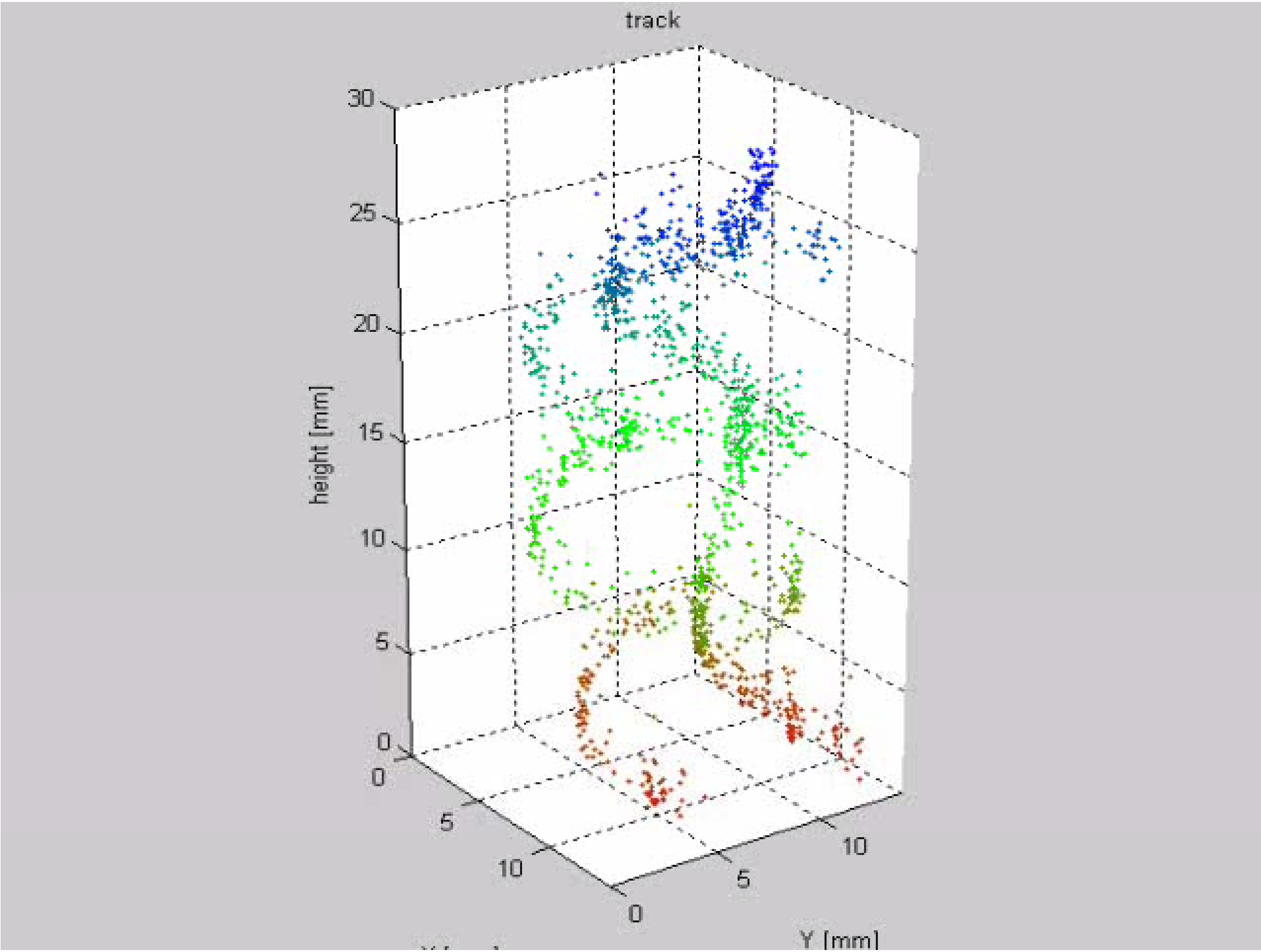
Latest results



B = 0.2 T

Vertical field lines

Electrons from ^{90}Sr source

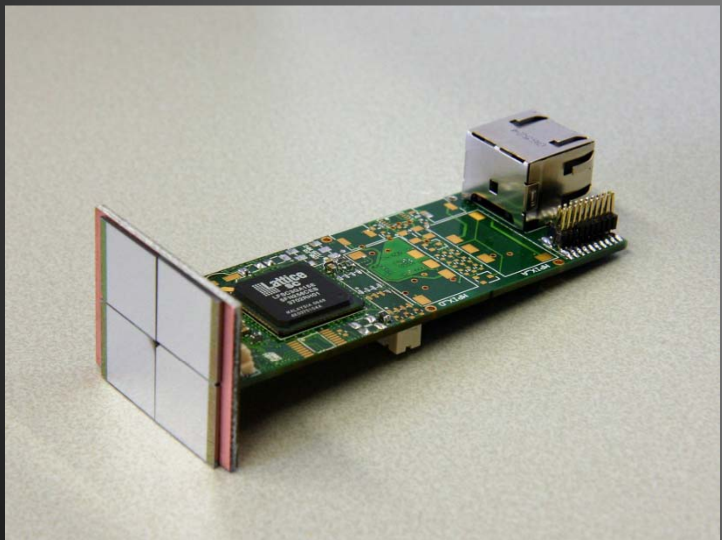

track
height [mm]
30
25
20
15
10
5
0
0
5
10
0
5
10
Y [mm]

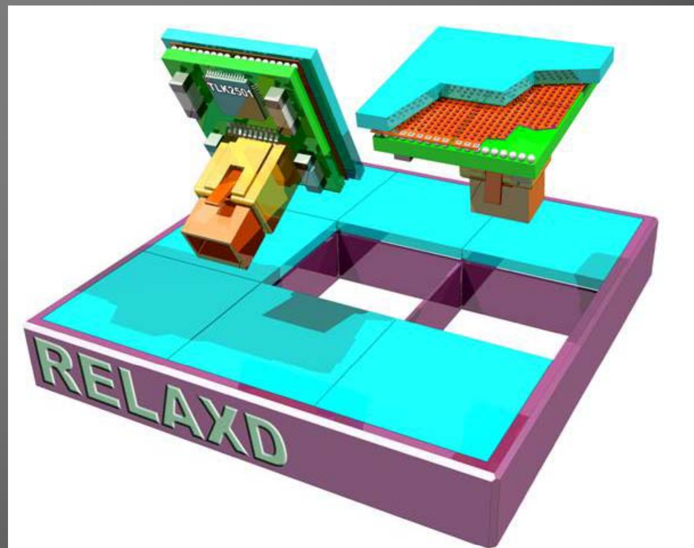
And for now

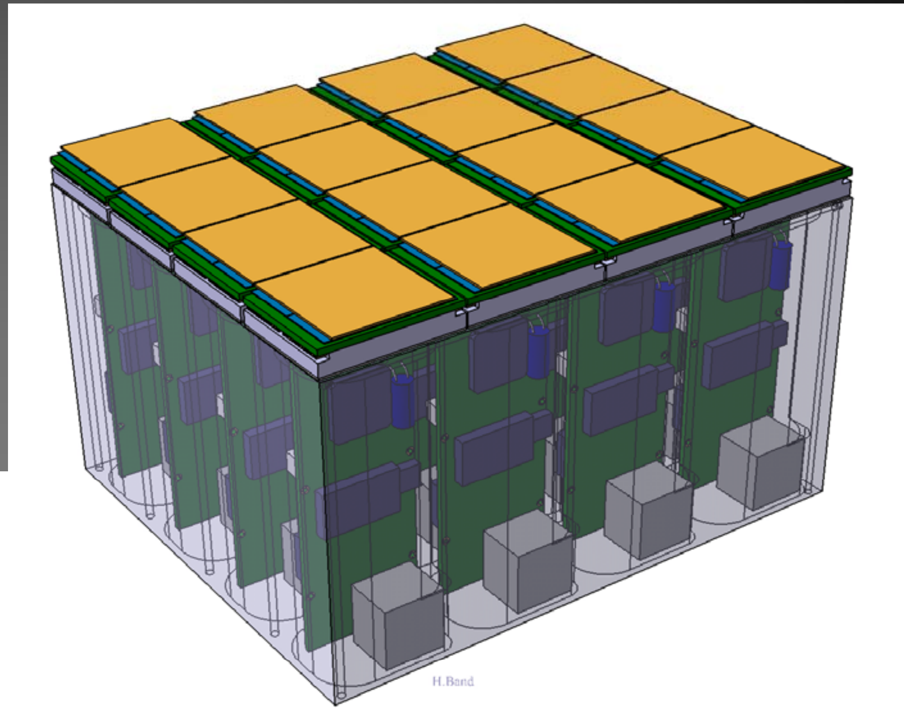
- Next quad: 4 chips+InGrid on a board

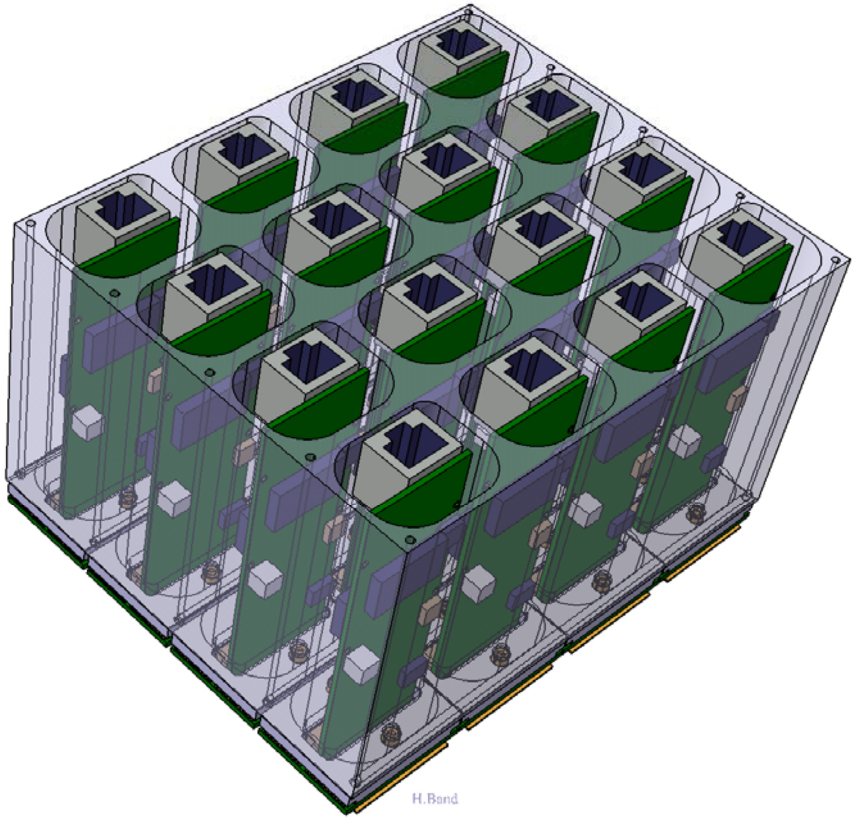
◉ ReLaXd

CO_2 cooling






H.Band

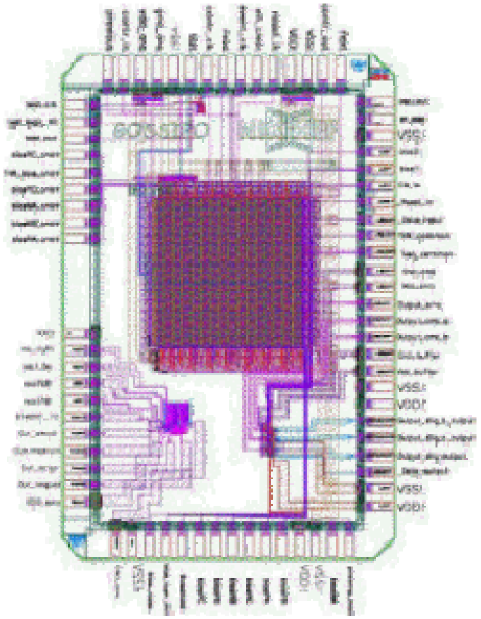

H.Band

TimePix-2

Gossipo-2 MPW

600 MHz osc
in each pixel

Low-noise,
low power analog
input



Medipix-1

Medipix-2 — 250 nm technology

TimePix

Medipix-3 — 130 nm technology

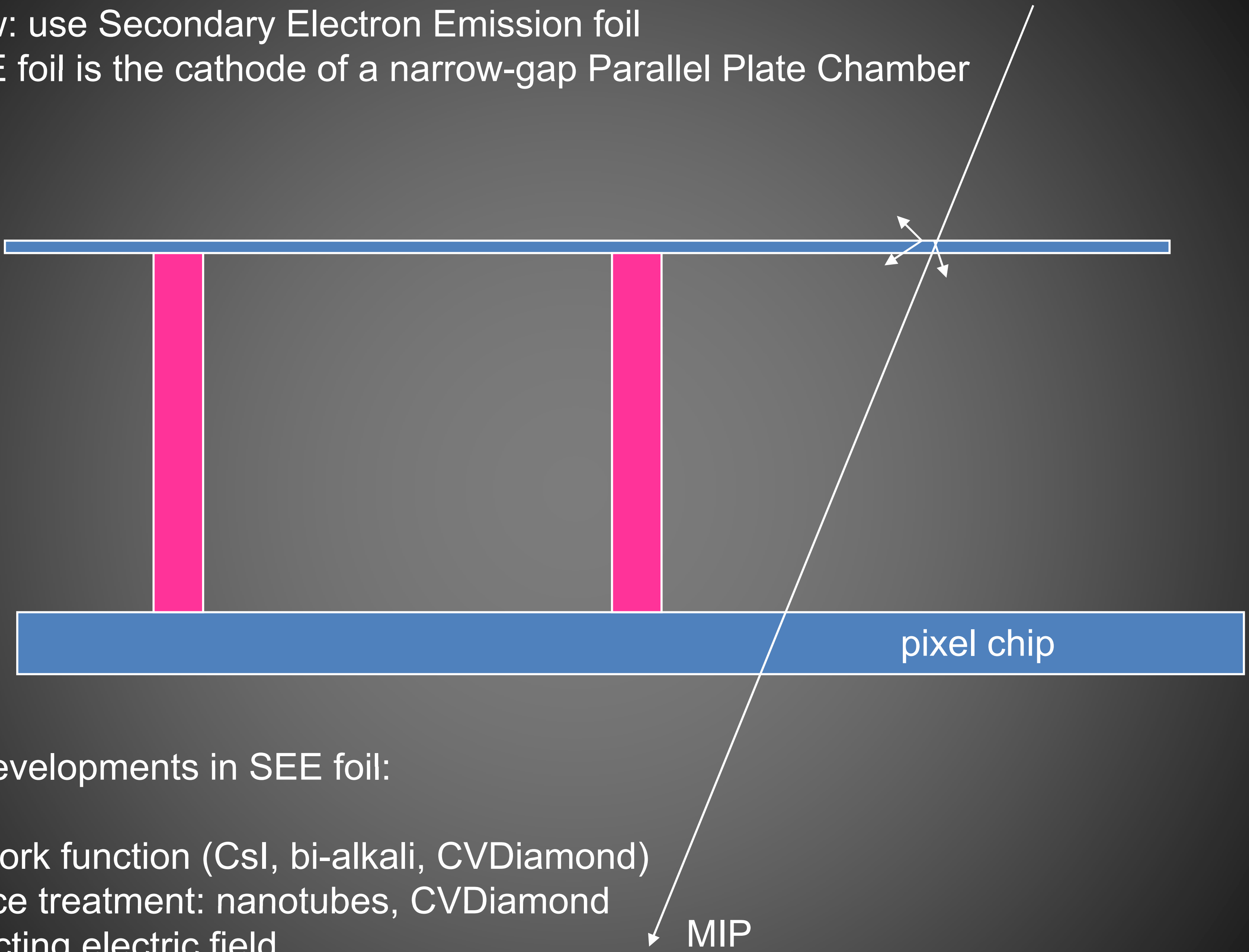
TimePix-2

TimePix-2:

- TDC per pixel: σ = 1 ns
- ‘ADC’ per pixel: TimeOverThreshold
- noise: 80 e- eq.
- discharge protection circuit
- fast (trigger enabled) readout

Essentially ALL info on primary electrons in gas is extracted!

New: use Secondary Electron Emission foil
SEE foil is the cathode of a narrow-gap Parallel Plate Chamber



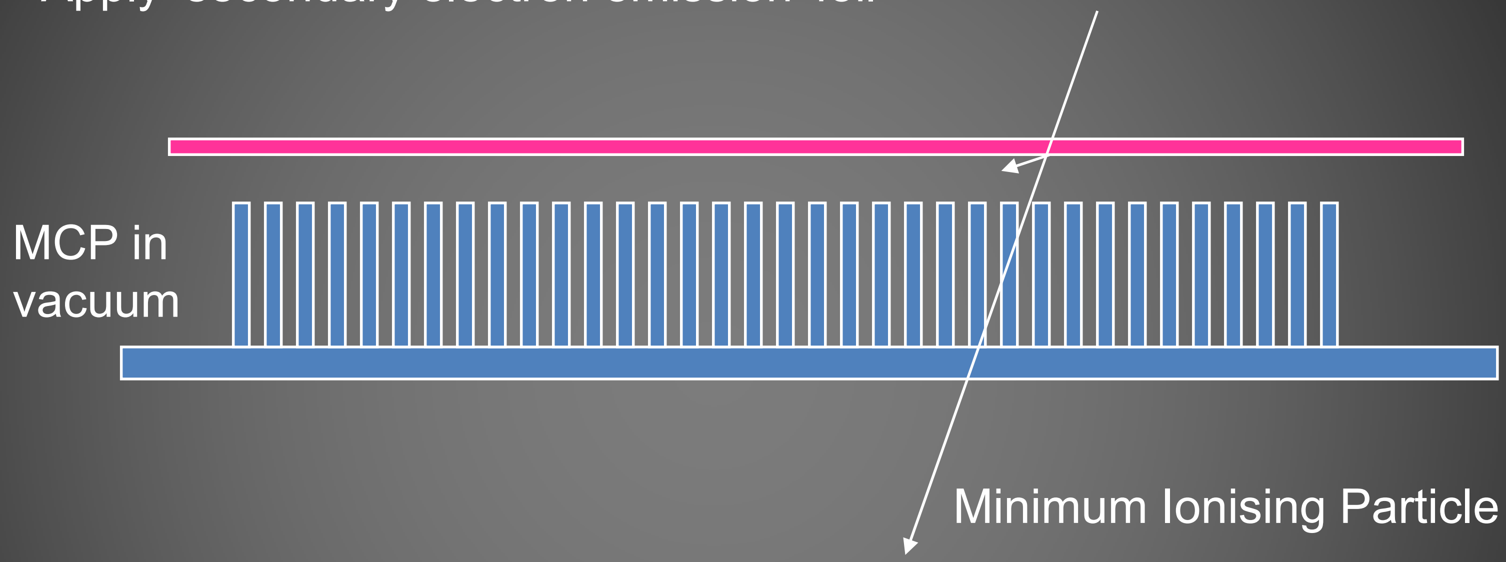
New developments in SEE foil:

- low work function (CsI, bi-alkali, CVDiamond)
- surface treatment: nanotubes, CVDiamond
- Extracting electric field

Now wires are eliminated from gaseous detectors ('wire chambers')

Replace InGrid by Micro Channel Plate (wafer post processing tech.)

Apply 'secondary electron emission' foil



Gasless track detector

Conclusions and plans

- Gossip has shown to work with the PSI-46 CMS Pixel FE chip
- With a 20 µm SiProt layer, CMOS chips are spark proof

Next steps:

- Build from PSI-46 + SiProt + InGrid
  - Demo 'beam telescope': testbeam work
  - Demo ATLAS B-layer: to be installed in hot spot in ATLAS near beam pipe
  - Proto Pixel detector as ATLAS Upgrade

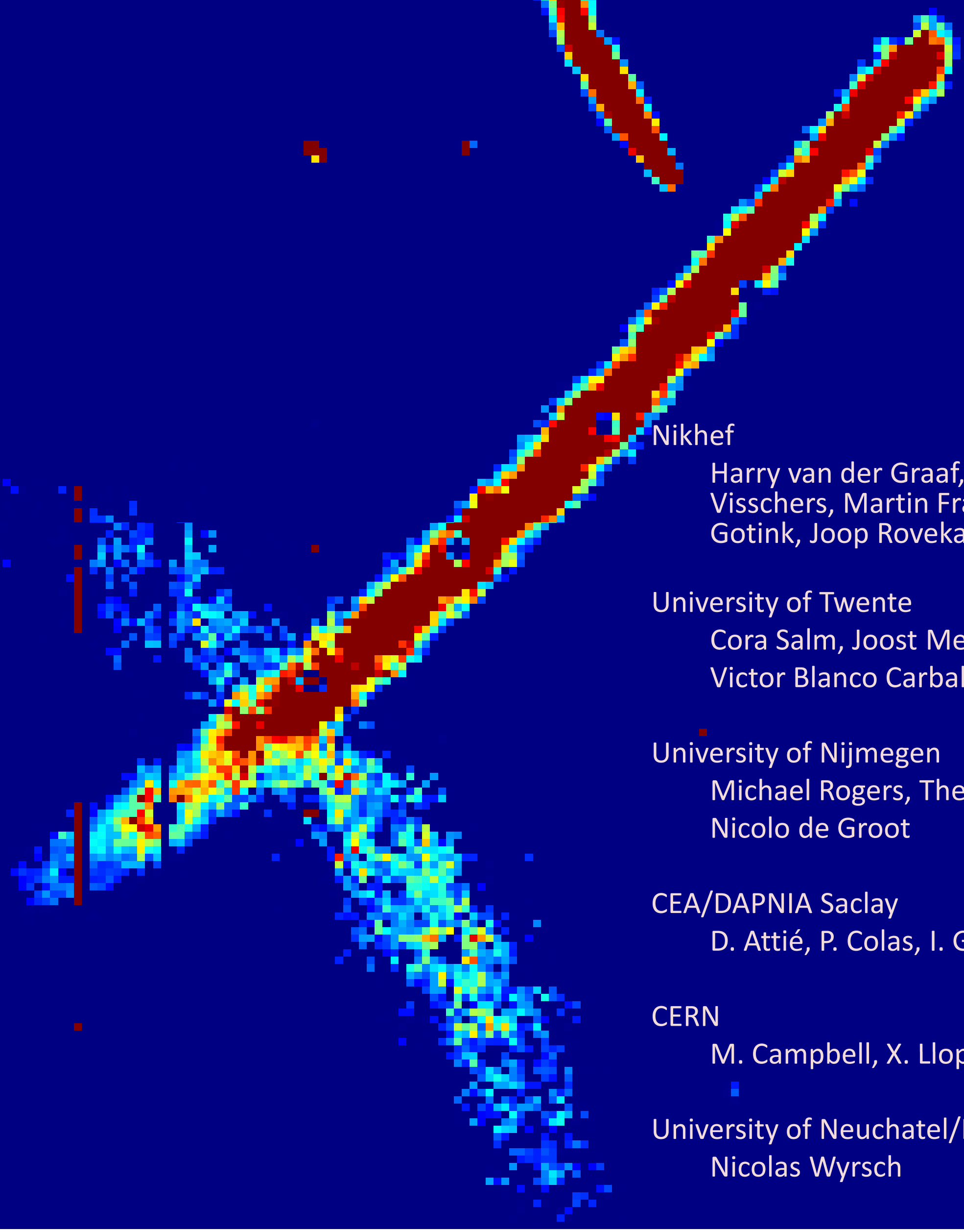
- With TimePix & TimePix-2 chips:
  - DICE: µTPC for nuclear physics
  - Next-Quad
  - ReNextD (= ReLaXd + Next-64)

- TimePix-2 chip development

- Gas ageing studies: testing Si containing compounds (SiO_2, SiH_4, SiC_nH_m)

- In framework of CERN R&D project RD51 (kick-off Worshop @ Nikhef April 2008)
  - Simulations
  - testbeam work

…..but it is hard to convince the Si detector community that the 21st century may come up with new technology…….



Nikhef

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